USING GIS AND LAND USE DATA TO SELECT CANDIDATE REFERENCE SITES FOR STREAM BIOASSESSMENT

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Using GIS and Land Use Data to Select Candidate Reference Sites for Stream Bioassessment

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I have submitted this thesis in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

GIS was used to select candidate reference sites in Georgia to characterize the reference condition by sub-ecoregion for a rapid bioassessment of streams statewide. Instead of relying on best professional judgment or previous knowledge of a limited number of sites, we performed an objective evaluation of cumulative impact on all catchments using land use data sets. These included road and impoundment data from DLGs and Multi-Resolution Land use Consortium data. Land use impairment was measured as percentages of forest, urban, pasture, row crops, and barren area for both the entire catchment and for 10, 40, and 130-m riparian buffers, road and impoundment density and stream/road crossings. Sites were then ranked by land use impairment, with the least impaired selected as candidate reference sites. The larger buffers, impoundment density, and stream/road crossing criteria were the least able to predict minimal impact, and were weighted less. Water chemistry, benthic macroinvertebrates, and physical habitat results demonstrated that 74% of the sites selected using this method met reference site criteria of other states. These data also demonstrated that these sites were equal to, or better than, sites identified by using best professional judgment. Possible reasons for the misidentification of sites are changes in land use since the data collection and the lack of a direct correlation between moderate human land use and stream habitat impairment.

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INTRODUCTION.

Background of Bioassessment and the Reference Condition.

Our nation's need to improve the condition of streams is mandated by congress in the Federal Water Pollution Control Act and as modified as the Clean Water Act (CWA) (33 U.S.C. § *et seq.*). The objective of both acts "is to restore and maintain the chemical, physical and biological integrity of the nation's waters." (CWA, § 101(a), 33 U.S.C., 1251(a), 1999). To meet these objectives, the law requires states to develop and enforce water quality criteria based on biological assessment (bioassessment) in accordance with methods published by the Environmental Protection Agency (EPA), whenever numerical criteria for toxic pollutants are unavailable (CWA, §303(c)(2)(B), 33 U.S.C., §1313(c)(2)(B), 1999). The law also requires streams to be assessed for non-point source pollution (NPS) (CWA, § 319, 33 U.S.C., §1329, 1999) and that they report the current quality of surface waters and the extent that they will support wildlife to the EPA (CWA, §305(b)(1)(B), 33 U.S.C., §1315(b)(1)(B), 1999). To support these requirements the EPA has published guidelines on developing bioassessments, the *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish* (Barbour et al. 1999) and biocriteria, *Biological criteria: Technical guidance for streams and small rivers* (Gibbson et al. 1996). Bioassessments, and their resulting biocriteria, are effective methods for assessing water quality because they provide a way of integrating the chemical, physical, and biological effects on water quality by directly measuring biologic integrity and indirectly measuring

physical and chemical integrity. This indirect measurement of chemical integrity may actually be more representative of the true integrity of the stream than base flow chemical data since chemical composition varies widely over time, both seasonally and during storm flows (Bolstad and Swank 1997; Johnson et al. 1997).

The Rapid Bioassessment Protocol (RBP) is a way of gathering, analyzing and reporting biological, chemical, and physical habitat data to support a number of management decisions to improve water quality. The basic output of these assessments is a characterization of the amount of impairment on an aquatic system (Fore et al. 1996). This information then would support management decisions such as evaluating non-point source pollution and the Total Maximum Daily Loads (TMDLs) and Best Management Practices (as defined in CWA, §303(d)) to control non-point sources of pollution. It would also identify areas and standards for restoration, isolate causes and sources of impairment, monitor trends, provide risk management, and help set priorities for restoration (Barbour et al. 1999).

The first step in developing a rapid bioassessment protocol for a specific area is to establish a control, or some desired state of ecological integrity, which is usually the best available condition, referred to as the "reference condition" (Resh et al. 1995). The reference condition is defined as "the condition that is representative of a group of minimally disturbed sites organized by physical, chemical and biological characteristics" (Reynoldson et al. 1997) and serves as a control for all other comparable streams. The reference condition is then

characterized by measuring its chemical, physical and biologic attributes. These same variables can then be measured at known impacted sites in the same geographic region to determine which biological measurements best detect the difference between reference and impaired conditions. These measurements (or metrics), can then be combined into a single number describing the amount of impact on any system that shares the same potential natural condition, usually described in terms of an ecoregion. Ecoregions are "regions of relative homogeneity in ecological systems or in relationships between organisms and their environment" (Omernik 1987). Richards et al. (1997) cautioned that metrics of this sort must be calibrated to each region if they are to detect changes due to anthropogenic impact from natural variability.

Characterizing Reference Conditions: Selection of Regional Reference Sites.

Reynoldson et al. (1997) summarized and reviewed the seven main methods used to characterize the reference condition presented in works by Hughes (1995) and Johnson et al. (1993) (see table 1-1). Both Reynoldson et al. (1997) and Hughes (1995) concluded that the primary method for determining the reference condition should be regional reference sites, because of their greater applicability. Regional reference sites are defined as a group of sites that will characterize the best attainable condition for a given region (Reynoldson et al. 1997).

Table 1-1. Summary of approaches for determining reference condition of streams adapted from Reynoldson et al. (1997) based originally on Hughes (1995) and Johnson et al. (1993).

Approach	Application	Limitations
Regional reference sites	Ordination and indicator analyses are used to determine representativeness of reference sites; acceptable levels of disturbance must be determined	Aquatic ecoregions are applicable to whole faunal assembly but there is some difficulty in applying ecoregions to particular communities; habitat classifications are still needed
Historical data	Useful if sites have been periodically resampled, or if making general statements about conditions	Usually limited to a single invertebrate community; often comparisons with historical data only can reflect serious deterioration; data incomplete or method sometimes unknown
Paleo-ecological data	Essentially limited to lakes, diatoms and chironomids	Poorly suited to streams; diatoms, the most widely used group, are affected by changes in water quality but perhaps less from changes in habitat structure or introduced species
Biotic indices	For comparison with predetermined hierarchy of values	Conditions represented by indices may not be obtainable because habitat differences; tolerance usually developed for organic contamination
Experimental laboratory data	Relationships between test and species and some stressors (specific toxins, temperatures, etc.) are well known so field data may be used to exclude some reference sties	Data not applicable to entire invertebrate communities and are unsuitable for systems disturbed by other stressors
Quantitative methods	Plotting metric values against disturbance or natural variables can establish reference conditions through curve fitting	Outliers, uneven distribution of data, and absence of data from minimally disturbed sites can distort models
Best Professional Judgment	Convening expert panels to determine reference conditions and peer review of data and conclusions	Value of judgment is a function of scientists' expertise and the quality of data supplied to them

To determine the appropriate region for comparisons, each area of interest is initially divided into ecoregions and then sub-ecoregions that are delineated by grouping areas with similar climate, physiography, geology, soils, and vegetation (Hughes et al. 1986; Omernik 1987). These sub-ecoregions are initially tested to see if they adequately group streams by common or distinctive physical and chemical characteristics. The sites least impacted by human activity are then chosen within each sub-ecoregion, and then these are sampled and characterized to establish the reference condition.

The certainty that a stream is the least impacted is only possible if the condition of all streams is known or is estimated based on probabilistic sampling. This knowledge of stream condition has been used to very accurately define the reference condition, resulting in very sensitive metrics for determining whether or not a stream is impacted. In an analysis of the streams of the Umpqua National Forest and Roseburg and Medford Districts of the Bureau of Land Management by Fore et al. (1996) used data on logging, in stream condition, and taxonomic richness to choose the seven least impacted streams from a set of 80 streams. The Maryland Biological Stream Survey, using probabilistic sampling design to collect data from over 1000 streams, established a set of criteria that described the best available conditions found within the state. These criteria (table 1-2) were used to describe an adequate number of minimally impaired sites (Stribling et al. 1998).

Table 1-2. Maryland Reference Site Criteria adapted from Stribling et al. (1998).

Criteria
pH ≥6 (if blackwater stream, ph<6 and DOC ≥8 mg/l)
Acid Neutralization Capability (ANC) ≥50 meq/l
Dissolved O2 ≥ 4 ppm
Nitrate-N ≤4.2 mg/l
Urban Land use ≤20% of catchment area
Forested land use ≥25% of catchment area
Instream habitat optimal or sub-optimal
Riparian buffer width ≥15m
No channelization
No point source discharges
Remoteness rating optimal or sub-optimal
Aesthetics rating optimal or sub-optimal

While results of the previous comprehensive studies are encouraging, I believe the greatest need for determining reference conditions is in those larger regions and states where less data are readily available. For these areas, a more practical method is to identify those streams with the greatest likelihood of being among the lowest impacted and then measure biological and physiochemical parameters to determine their actual condition. These streams are candidate reference sites. The difficulty in determining what sites are reference was summed up by Resh et al. (1995), "If reference sites could be distinguished easily from test sites, impairment could be assessed without any measurement." The ability of science to define reference sites was identified as one of the three major limitations of the current system of establishing biocriteria (Science Advisory Board (SAB) 1993).

Hughes et al. (1986) recommend the following six-step process for selecting candidate reference sites:

1. The amount of human disturbance for each possible catchment is determined and those with large amounts of disturbance are eliminated.

2. Stream sizes are then quantified, evaluating catchments by area or by annual discharge and comparing only sites within an order of magnitude of each other.

3. Stream types are then characterized by distance from receiving waters, drainage pattern, and gradient, retaining those that are typical for the region.

4. and 5. Refugia and migration barriers are located to help determine where unimpaired communities most likely are.

6. Suggest candidate reference sites.

This filtering process should have rejected degraded or atypical streams and produced a final product, a list of candidate sites, ranked by level of disturbance. While Hughes et al. expressed the need for an objective procedure to select the candidate sites, and did recommend some qualitative indicators of disturbance, they did not recommend a method for determining the amount of disturbance in each catchment.

Hughes (1995) modified his original method to an iterative process composed of the following steps:

1. Define areas of interest, using natural boundaries whenever possible.

2. Define water bodies of interest by type (lake, stream, wetland) and size.

3. Delineate (select) candidate reference catchments, focusing on rejecting impacted sites while retaining minimally disturbed sites. This step is done by

evaluating available data / maps, by remote sensing, and by obtaining input on candidate sites from local experts and managers.

4. Conduct aerial and field reconnaissance to choose sites and confirm selections. Hughes recommends the use of a qualitative habitat evaluation form.

5. Subjectively evaluate quality of candidate reference sites

6. Determine the number of sites needed.

7. Quantitatively evaluate reference sites.

The objective of this process is to locate and characterize the least disturbed and most representative unimpaired sites possible. Hughes recognized that this task is very difficult, especially in extensively disturbed regions. He also urged increased objectivity in determining the reference condition, but recognized that the process still relies heavily on professional judgment (in terms of available time and budgets). However, regardless of these recommendations, reference sites often have been more subjectively chosen and often are more impaired than is desirable (Hughes et al. 1986, Hughes 1995).

The characterization of reference conditions initially suffered from a lack of feasible methods to determine the extent and degree of impairment at all possible sites. The approach of analyzing all streams to define the reference condition is problematic in most situations in terms of cost and time available. However, not considering most of the possible sites results in a greater chance of the reference sites not actually representing the best attainable condition. Montana limited its search for reference sites to only sites where fish data were

already available, resulting in selecting only 38 streams as reference sites for the entire state (Gibson et al. 1996).

Hughes et al. (1986) recommended that the location of candidate sites be discussed with knowledgeable resource managers and scientists, questioning them about the conditions of local streams and about the location of other candidate sites. This recommendation, in absence of a viable alternative, has been used extensively for selecting candidate reference sites. Best Professional Judgement (BPJ) relies on the knowledge of local experts or on data gathered in previous studies that indicates where the best available aquatic communities are located. Surveys of all of the local resource managers and scientists, including fisheries biologists, hydrologists, geologists, and entomologists, are accomplished by telephone interview or by mailed survey (Barbour et al. 1999; Mrazik 1999). Appendix D of the EPA's the *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish* (Barbour et al. 1999) provides a set of written questionnaires designed to gather data on stream conditions from local experts. In many cases, the resource agency trying to establish the reference conditions already has extensive data collected from attempting previous studies or has its own experience that indicates where potential reference sites are located (Stribling et al. 1998). The Texas Aquatic Ecoregions Project performed by the Texas Natural Resource and Conservation Commission (TNRCC) provides an example of the selection of reference sites (Hornig et al. 1995). The TNRCC analyzed maps of land surface form, potential vegetation, soil type, and land use to choose

the catchments that lacked urban development, channelization, and flowed through catchments with natural vegetation for that region (Hornig et al. 1995). Bailey et al. (1998) used streams without any point sources of pollution (mining activity) as reference sites, since that was the predominate type of anthropogenic impact in the central Yukon Territory.

Reference sites chosen by BPJ are often limited in both number of stream sites chosen and quality of the site characteristics because of the limited amount of previous research and the fact that BPJ is limited only to streams that are generally easily accessed (Hughes 1995). Since ease of access (road/steam crossings) is a form of anthropogenic disturbance, sites chosen by BPJ may not always be the least impacted streams available. This suggests that a relatively comprehensive yet unbiased analysis of physical, chemical, and biological features in each geographic region might provide a more complete suite of candidate reference sites.

Until recently, the analysis of large amounts of geographic data was time consuming for areas as large as states (Hughes 1995). Since the ability of any bioassessment method to establish standards for clean water and healthy ecosystems is only as good as the reference characteristics it is built upon (Hughes 1995), there needs to be a rapid and relatively inexpensive method to determine the condition of streams, in turn focusing effort on the conditions of the best streams available.

Assessing Impact Using the Synoptic Approach

The synoptic approach of determining the amount of cumulative impact was originally developed as a framework for comparing landscape units that quickly determines the relative amount of anthropogenic impact on a wetland (Abbruzzese and Leibowitz 1997). This approach is a compromise between the need for rigorous results and the need for timely information and is appropriate when little quantitative information is available, the cost of improving these data is high, there is an urgent need to make decisions, and the cost of a wrong answer is low. The steps to conduct a synoptic assessment are:

1. Define the goals and criteria of the assessment.
2. Define the synoptic indices to be used (i.e. types of impacts).
3. Select the landscape indicators that allow an assessment of the indices.
4. Conduct the assessment by analyzing maps and other spatial data.
5. Report the results of the analysis, usually in the form of a map.

Bolstad and Swank (1997) demonstrated how this approach could also be used to assess the cumulative impacts of NPS pollution on water quality in streams. Their results showed a consistent and cumulative decrease in water quality with increasing non-forest land use, principally building and road density and agricultural land use.

The synoptic approach to assessing the amount of anthropogenic disturbance to streams is based on the idea that disturbance can be estimated by looking at the land use of the catchment that feeds into the stream. It has been argued that

the conditions of the catchment influences or controls the conditions of the stream in the catchment (Richards and Host 1994), so it follows that the amount of disturbance in the catchment should predict the extent or intensity of disturbance in the stream. With recent advances in remote sensing and geographic information system (GIS) technology, many studies have supported this inference. Anthropogenic land use affects stream communities both directly through changes in water chemistry by affecting the amount of metals and nutrients (Bolstad and Swank 1997), as well as through suspended sediment loading (Lenat and Crawford 1994; Johnson et al. 1997). The modification of habitat through the indirect effects of land use has also been documented (Richards et al. 1996). A clear, negative, correlation between the amount of urbanization in a catchment and a stream's biological integrity has been shown in several studies (Lenat and Crawford 1994; Wang et al. 1997; Kennen 1999; Roth et al. 1999) while a positive correlation has been shown with the proportion of the catchment that is forested (Roth et al. 1996; Wang et al. 1997; Rothrock et al. 1998; Kennen 1999; Roth et al. 1999).

The correlation between agricultural land use and stream integrity is much less clear. While some studies have shown that agriculturally dominated catchments have impaired biological integrity (Richards et al. 1996; Roth et al. 1996; Rothrock et al. 1998), Kennen (1999) did not. Lenat and Crawford (1994) found changes related to the amount of agricultural land use in benthic macroinvertebrates but not in fish communities. Roth et al. (1999) found a positive correlation between the fish Index of Biotic Integrity (IBI) and Hilsenhoff's

Biotic Index and the amount of agriculture, but no correlation between their benthic IBI and the amount of agriculture. Lammert and Allen (1999) found a weak correlation between the amount of agriculture and fish IBI, benthic IBI, and four other common metrics, but only for land use within 100 m of the stream. Wang et al. (1997) found the impact on fish communities to be nonlinear, with the effects of agriculture only becoming apparent in catchments with more than 50% agriculture. Rothrock et al. (1998) also showed that both increasing road density and silviculture lead to lower biologic integrity. Schnackenberg and MacDonald (1998) also found a strong correlation between the number of road crossings and the percentage of fine particles in the substrate that would affect aquatic communities. They found a weaker correlation between fine particles and the amount of clear-cut forests.

Even though the relationship of stream condition to catchment condition seems clear enough, several factors make the relationship complicated. Several studies have shown other factors to have equal or greater impact than land use patterns on aquatic communities, including geology, topography, and geographical characteristics (catchment area, altitude, and length) (Richards et al. 1996; Johnson et al. 1997; Bailey et al. 1998). There are also interactions between these geologic or geographic features and land use that are difficult to separate. Most investigators have concluded that the catchment's land use has more impact on stream communities than the land use of the riparian buffer (Roth et al. 1996; Allan et al. 1997; Wang et al. 1997; Kennen 1999). However, Richards et al. (1997) found reach scale properties more predictive of species

traits than catchment properties, although the catchments may have had an indirect effect on the reach scale properties. Lammert and Allen (1999) also found much more of the variance in stream communities explained by the type of land use within a 100-m riparian buffer than in the entire catchment. Since Lammert and Allen's results were opposite of those found by Roth et al. (1996) on the same stream, they suggested that the relative importance of buffer versus catchment might be a function of the scale of the investigation. Lammert and Allen proposed that larger scale, less spatially expansive, investigations are more sensitive to local changes in physical habitat than smaller scale investigations. The stronger relationship of catchment characteristics to the stream community structure found by others may also have been a function of the precision of the data used. The other studies described previously (Roth et al. 1996; Allen et al. 1997; Wang et al. 1997; Kennen 1999), used data with a minimum mapping unit greater than 2 ha and so were only able to examine the effect of 100-m buffers. A more fine grain data set would allow the analysis of smaller and perhaps more influential buffer zones.

If the amount of anthropogenic land use within a catchment is going to be used to predict the relative amount of stream impairment, then these geologic or geographic factors that also effect stream communities must be controlled during analysis. Using an a priori classification, by sub-ecoregion, and examining stream catchments within a single order of magnitude, variability in these geologic or geographic factors will by taken into account. Combining catchment-wide land use with measurements of direct impact on streams caused by road

crossings and alterations within the riparian zone of streams, such as roads and agricultural land use should create a measure of the extent of impairment to a stream's ecosystems relative to other systems in the same sub-ecoregion.

Schnackenberg and MacDonald (1998) provide an example of this approach by defining their reference sites in terms of cumulative land use and direct impact. They arbitrarily selected streams with less than 2% of the catchment clear-cut, and density of road crossings and roads within 60 m of streams less than 0.25/km^2 as their reference sites. Mrazik (1999) also used land use data, but as a filter for sites that were identified by BPJ instead of as a site selection method. He used road density as a measure of anthropogenic impact which allowed sites to be ranked in terms of amount of impact. Then the top 25% were verified through field reconnaissance and the collection of biological data. He recommended that other land use data be used in the future to provide a better measure of impact, including current and historic land use and road crossings.

Objectives.

This research was part of the second phase of the Georgia Ecoregions Reference Sites Project being conducted for the Georgia Department of Natural Resources (GA DNR) by Columbus State University (CSU) as described in the quality assurance program plan (QAPP) (CSU 2000). The project was performed in four phases and stated that the second phase had two objectives. The first was "the characterization of the reference stream condition in each of the major ecoregions and sub-ecoregions" for wadable streams in the state of Georgia

(CSU 2000). The second was "to collect and analyze chemical and biological water quality samples at least impacted sites that are representative of ecological regions across the state" to "establish ecoregion-specific biological criteria that are representative and attainable" (CSU 2000). The purpose of my research was to develop an objective method of selecting these least impacted sites to be possible candidates for regional reference sites that would in turn characterize the reference condition. Since it had been shown by the studies described earlier that the amount of stream impairment is correlated with the land use of the catchment, I based this method on using remotely sensed land use data analyzed with a GIS to select the catchments with the lowest human land uses, and thus the best potential of being the least impaired. This method selected these possible candidates from all catchments that fit within a single classification based on size and ecoregion, and then ranked these sites based on their amount of cumulative impact, choosing the best-ranked sites as possible candidate reference sites.

MATERIALS AND METHODS.

Study Area.

The study area included the state of Georgia and the area of any catchments shared with the neighboring states of Tennessee, Alabama, North Carolina, and Florida, covering an area of 153,169 km^2. South Carolina did not share any catchments of the size evaluated in this study. This area lies across five ecoregions as described by Omernik (1987): (a) the Blue Ridge Mountains, (b) the Ridge and Valley, (c) the Cumberland Plateau, (d) the Piedmont, (e) the Southeastern Plains, and (f) the Coastal Plains. These ecoregions categorize the major differences found in topography, physiography, climate, elevation, hydrology, vegetation, wildlife, land-use, and surface geology as reflected by soils across Georgia (see table 2-1, Descriptions of Georgia Ecoregions). Each of these ecoregions has been further divided into sub-ecoregions, reflecting higher resolution changes in these variables. The sub-ecoregions divide the state into 28 areas, ranging in size from 290 to 31,590 km^2 (see figure 2-1, Sub-ecoregions of Georgia).

Some of these sub-ecoregions were excluded from the study area. The flood plain ecoregions (65p & 75i) were removed from the study area because they contained a limited number of streams of the size of interest (see discussion of catchment size below). Sub-ecoregion 75g, the Okefenokee Swamps did have enough streams of the appropriate size and could have been evaluated. However, because the sub-ecoregion exists almost entirely within a national

Table 2-1. Descriptions of Georgia Ecoregions. Data for elevation and slope represent the range for ±1.5 Standard Deviations from the mean.

Ecoregion Code	Ecoregion Name	Geology	Elevation (Ft)	Slope (degrees)	Drainage Pattern	Principle Land-use / Vegetation	Climate
45	Piedmont	Metamorphic	346-1335	0-28	Dendritic	Mixed Forest, Silviculture, & Urban	Mesic - Xeric
65	South-eastern Plain	Sedimentary (Cretaceous - Miocene)	110-517	0-16	Dendritic	Agriculture, Pine Forest, & Silviculture	Mesic - Xeric
66	Blue Ridge Mountains	Metamorphic	920-3114	8-60	Dendritic	Hardwood Forest	Mesic - Submesic
67	Ridge & Valley	Sedimentary (Paleozoic)	600-1031	0-33	Trellis	Hardwood Forest, Agriculture	Mesic - Submesic
68	Cumber-land Plateau	Sedimentary (Paleozoic)	1074-2108	0-50	Trellis	Hardwood Forest, Agriculture	Mesic - Submesic
75	Southern Coastal Plain	Sedimentary (Pliocene - Pleistocene)	0-206	0-4.5	Dendritic	Pine Forest, Agriculture, Silviculture	Mari-time

wildlife refuge there was no need to find reference sites for determining the amount of human impact on streams within the refuge. Also, because the swamp is a unique landscape within Georgia, reference sites are not needed for comparison to other streams in different sub-ecoregions. For these reasons, this sub-ecoregion was also excluded from the study area.

Data Sources and Preprocessing.

To conduct a statewide analysis of all wadable streams, data had to be

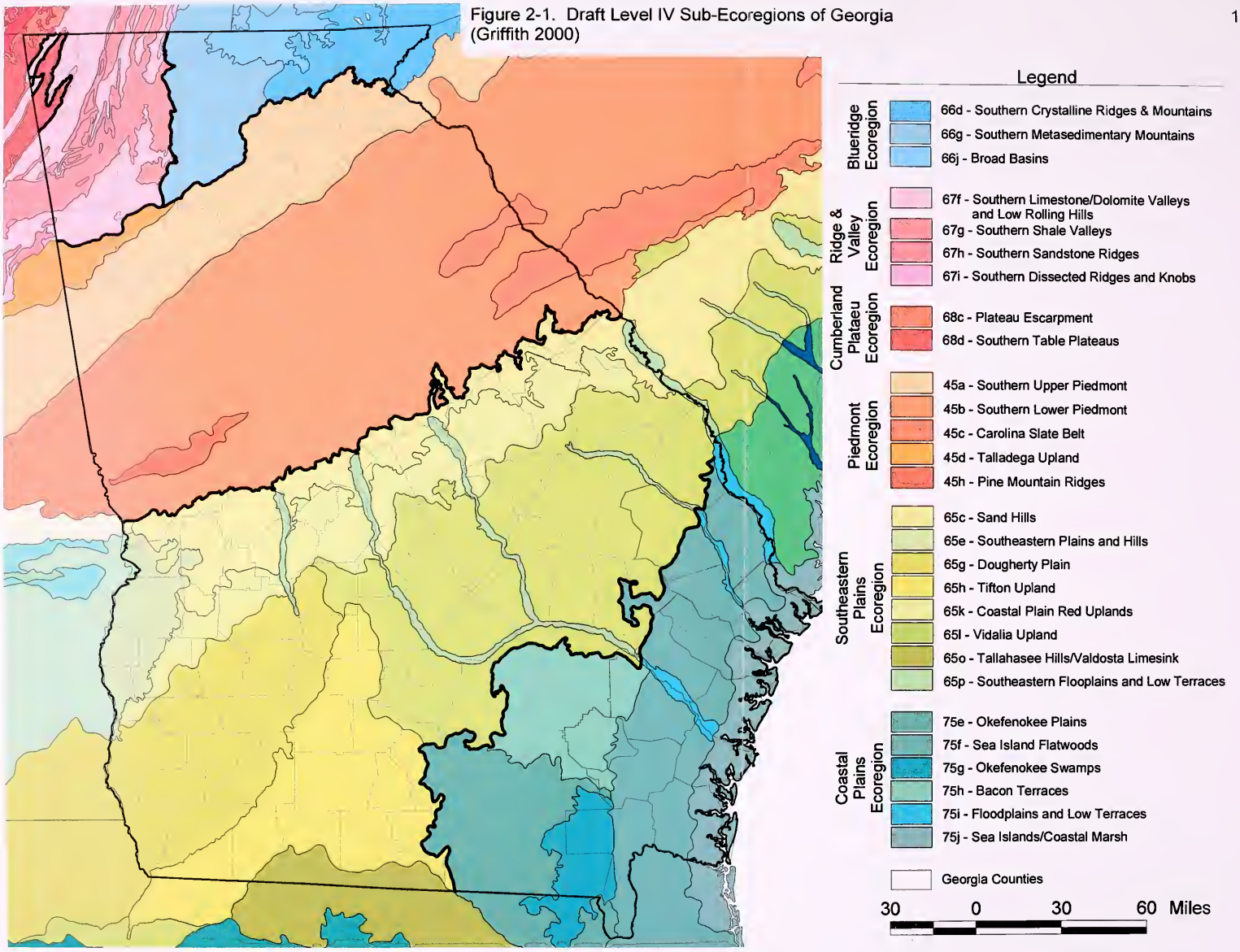


Figure 2-1. Draft Level IV Sub-Ecoregions of Georgia (Griffith 2000)

acquired that was both spatially expansive, inexpensive, and relatively detailed. Since the amounts of each type of stream impairment that occur in Georgia are unknown, the data was chosen to cover the widest array of potential impacts feasible. This included agricultural, silvicultural, and urban impacts, as well as road density, and road crossings. Data were also included on riparian conditions, point sources of pollution, and hydrologic impacts like in-stream impoundments.

Previous studies examining the links between land-use and water quality were often limited by the resolutions of the land-use data available. Richards and Host (1994) used the 1:250,000 scale Land use / Land cover Digital Data (LUDA) data with its 16 ha minimum mapping unit for their analysis. They concluded that higher resolution GIS data was needed to allow prediction of trends in macroinvertebrate assemblages. Other approaches using small-scale maps (1:100,000 and smaller) could also be missing many potential land-use impacts on water quality, such as the class IV (dirt) roads that appear only on larger scale maps. So, to capture as much detail as possible, the highest resolution data available was used.

At the same time however, a trade-off was made in data accuracy. Because data on a catchment were only going to be used relative to other catchments in similar environments, absolute accuracy was unnecessary. If the inaccuracies that occur were randomly or uniformly distributed, then the relative measurements of land use between catchments would be unaffected even if the absolute measurement of land use was not completely accurate.

The largest scale data available for the entire state was the 1:12,000 scale digital orthogonal quarter quadrangles (DOQQ) images. Although this would have been the most detailed information available for each catchment, it was both cost (>$15,000) and memory prohibitive for statewide coverage (greater than 163 Gb). In addition, there was no way to rapidly analyze these data on a statewide scale. However, a large assortment of both vector and raster data were available at 1:24,000 scale. Because of its cost (free) and ease of availability, I decided to do as much of my analysis as possible at this scale. However, data at that scale were provided only for counties, with the data projected into whichever Universal Transverse Mercator (UTM) zone covers the majority of that county. Each of the datasets downloaded (from the sources described below), were first decompressed, then imported from an ArcInfo export file or Spatial Data Transfer System (SDTS) format, then merged with other county datasets in the same projection, and finally changed to a geographic, or unprojected, format.

In the recent past, the competing demands for data that was both high resolution and had statewide coverage would have been insolvable. However, recent gains in desktop computing power, combined with a powerful GIS capable of spatial analysis, and the ready availability of free spatial data via the internet has made analyses like this one possible. All of the following analysis was done using a Pentium III desktop computer (Dell OptiPlex GX1) running Environmental Systems Research Institute (ESRI) ArcView 3.1 (ESRI 1999), a desktop GIS. A great deal of the basic statewide data described below was available at the

Georgia GIS Data Clearinghouse, a web site operated on a contract basis through the Board of Regents of the University System of Georgia with nodes at both the University of Georgia and the Georgia Institute of Technology. It provided most common data by county, for the entire state, free of charge to registered users. Because the GIS Clearinghouse only provided high-resolution data for Georgia, evaluating streams that crossed out of or into the state required additional data for the portion of those catchments that lay in other states. Data for these areas were downloaded either directly from the USGS, or from the GIS Data Depot, a licensed distributor of USGS data. A brief description of each of the data sets follows.

Digital Elevation Model (DEM) data were used to both analyze stream order and to delineate catchment boundaries. DEMs are raster data produced by the USGS that portray surface elevations using a 30-m grid. Each cell of the grid contains its mean elevation. The DEMs are produced by the USGS in standard 7.5 minute quadrangles with a UTM projection. These were then joined together by the Clearinghouse into coverages for each Georgia county and made available over the internet (Georgia GIS Clearinghouse 2000, USGS 1979). An ArcInfo Export File for each county was downloaded, decompressed, and imported into ArcView. Using the grid merge script in ArcView (see appendix B), each of these coverages was then joined with other coverages within the same UTM zone. The fact that Georgia lays in two UTM zones (16 & 17) created a problem for using these DEMs to analyze catchments that lay across the boundary of these two zones. Using the GIS to portray the county boundaries,

the major north-south hydrologic divide between Atlantic and Gulf drainages (as shown by the Hydrologic Cataloging Units (CUs)), and the division between the UTM zones, those counties that lay in one drainage, but which had the projection of that was predominate for the other, were selected. I then converted the DEMs of these counties into the predominate projection for that drainage of which that county was a part (e.g. counties that were part of the Gulf drainage which was mostly in UTM zone 16, but were projected in UTM zone 17, were then converted to UTM 16). This was done using Spatial Tools 3.3 command for Grid Warp (Hooge 1998). Each of these converted DEMs was then joined to the original DEM set in the other UTM projection to produce two DEM sets (one for each UTM projection) that were divided along hydrologic as opposed to geographic boundaries.

These DEM sets were then supplemented with additional individual DEM quarter quads downloaded from the GIS Data Depot. These data were only available in SDTS format and had to be converted using the extension "SDTS Import" (Goodwin and Tarboton 1999). The data values were then changed from metric to English units using Spatial Analysis's Map Calculator, and then joined with the appropriate DEM set.

Examination of the DEMs showed that they were not entirely error free, with many individual cells missing values. The cells of missing values (no data cells), would act as infinite sinks when the DEMs were used for hydrologic modeling, such as determining stream order and delineating catchments. Another problem for hydrologic modeling is the existence of sinks in the DEMs. Any cell that had a

value that was lower than all of the surrounding cells, would act as a sink during hydrologic modeling since the relatively simple models that I planned to use did not account for accumulation of water. While some of these sinks represented naturally occurring or manmade depressions, most of them were artifacts of the DEMs. These artifacts occur when narrow gullies exist in the drainage areas, so that while the stream is flowing downhill through the gully the DEM cell with the gully has a higher mean elevation than the upstream cell, giving the appearance on the DEM that water is flowing uphill. Another source of these artifacts occurs when two DEM quadrangles are joined and the downstream quadrangle, while internally consistent, has slightly higher elevations than the upstream quadrangle, producing a set of "dams" across all of the streams draining from one quadrangle to the next. The hydrologic modeling extension to ArcView has a script available for finding and filling any sinks that occur in a DEM by increasing the elevation of the cells in the sink. I modified this script to also find any no data cells, and then replace the missing elevation with the mean of the elevation of all the neighboring cells (see Appendix B).

Reference sites were needed by sub-ecoregion to assess the appropriateness of using these regions as areas for stream comparison. Glenn Griffith of the USDA Natural Resource Conservation Service (NRCS), at the EPA's National Health and Environmental Effects Research Laboratory (NHEERL) in Corvallis, OR, provided the data on sub-ecoregions (Griffith 1999, 2000). An initial draft of the sub-ecoregions was used at the beginning of the study that consisted of 28 sub-ecoregions. Sub-ecoregions were delineated in a manner similar to that

described by Omernik (1987), but at a higher resolution. The sub-ecoregions were delineated on fine scale differences in climate, physiography, soils, surficial geology, vegetation, land use, and water chemistry (Gallant et al. 1989). These data were provided as an ArcInfo Export File, which was then imported into ArcView. Then, each of the sub-ecoregions usefulness as a geographic area for comparing stream quality at the scale intended was assessed. As described earlier, three sub-ecoregions were excluded from the study area because of their unique hydrology (Okefenokee, Southeastern Plains Riparian, and Coastal Plains Riparian). Two other sub-ecoregions were not useful as separate geographic areas, since few streams originated in these areas but were mostly traversed by streams, and thus were highly connected to adjacent regions (see figure 2-2, Connectivity between Sub-ecoregions). Sub-ecoregion 68d (the South-Western Appalachian Escarpments) consisted of the dramatic hill slopes that lie between the South-Western Appalachian Plateaus (sub-ecoregion 68c) and the valley floors, mostly in Southern Limestone/Dolomite Valleys and Low Rolling Hills (sub-ecoregion 67f). While the sections of streams traversing the escarpments were significantly different from sections up or down stream in terms of slope and geology, they were not hydrologically independent of the upstream reaches on the plateau (sub-ecoregion 68c), and their quality should have reflected the amounts and types of land-use upstream. Thus, the two sub-ecoregions (68 c & d) were combined and treated as a single sub-ecoregion in subsequent analysis. This same rationale was applied to sub-ecoregions 67f (Southern Limestone/Dolomite Valleys and Low Rolling Hills) and 67i (Southern

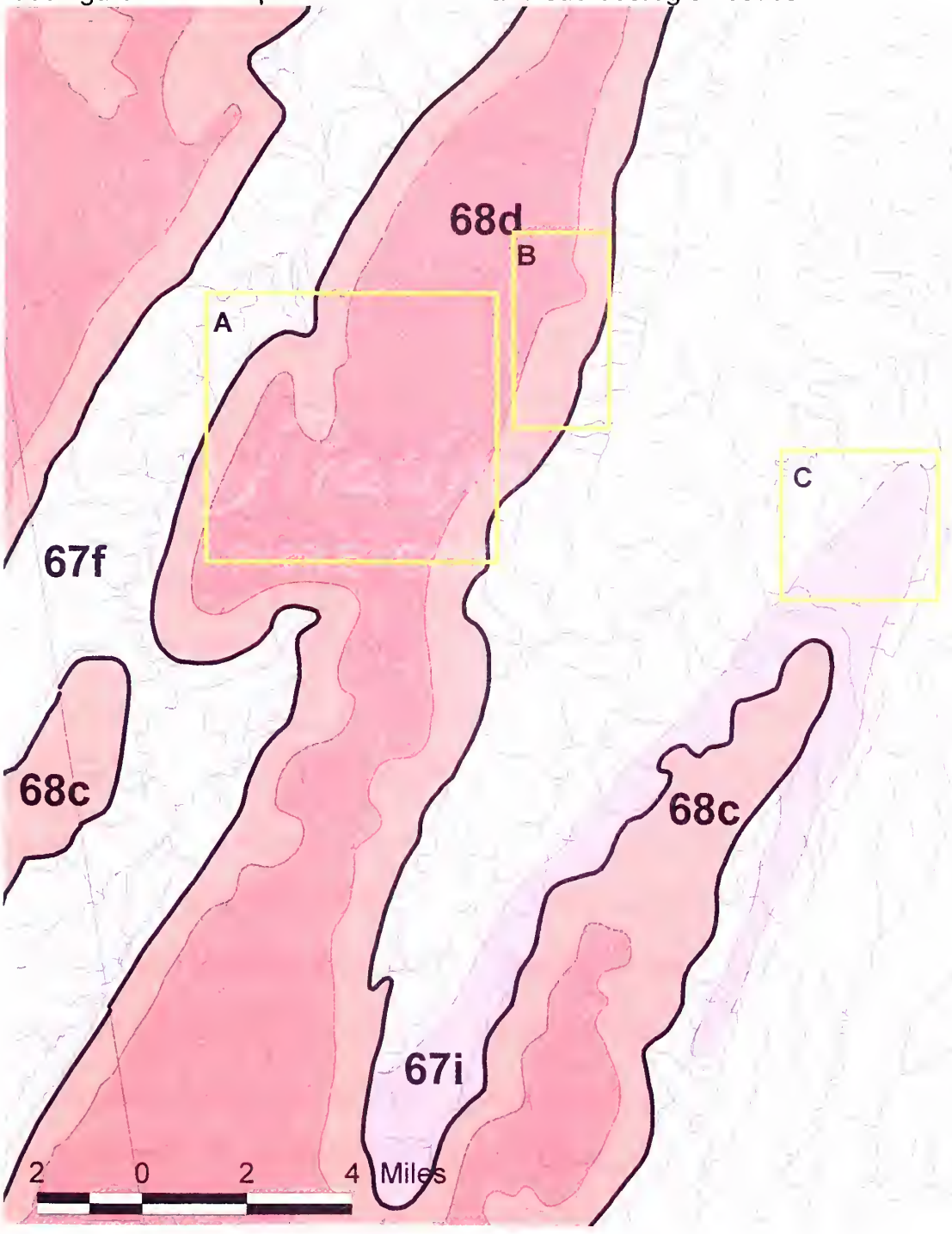
Figure 2-2. Connectivity between sub-ecoregions. Provides examples of connectivity between 67f and 67i and 68c and 68d:

A - Example of connections between streams in 68c and 68d.

B - Example of streams too small to use for comparison.

C - Example of connections between 67f and 67i.

Map is a subsection of figure 2-1, draft level IV sub-ecoregions of Georgia. See figure 2-1 for explanation of colors and sub-ecoregion codes.



Dissected Ridges and Knobs). Again these were contiguous ecoregions, with 67i generally being uphill of 67f. In this case however, the two regions were even more closely linked, sharing similar geology and topography. Because 67i was very narrow and contained only two catchments of the size investigated, it was merged with 67f for further analysis.

An updated draft (Griffith 2000) (figure 2-1) was provided after the initial selection of candidate sites was completed and actual field sampling of the sites had begun (November 2000). This update subdivided the Blue Ridge Ecoregion into three sub-ecoregions, and eliminated two sub-ecoregions, 65i (Fall Line Hills) in western Georgia and 63n (Mid Atlantic Floodplain and Low Terraces) in eastern Georgia. In both cases, the area of those former sub-ecoregions was subsumed into neighboring sub-ecoregions.

Hydrographic data were used to both delineate catchments for analysis and comparison as well as measuring the amount of anthropogenic hydrologic impact within each catchment. Hydrographic data of two types from two different sources were used. Linear data represented streams, and canals, while polygonal data represented lakes, ponds, reservoirs, and large rivers. The primary source for these data was the National Hydrography Dataset (NHD) (USGS 1998), which is based on a combination of the USGS's 1:100,000 scale Digital Line Graphs (DLGs) of hydrologic features and reach-related information from the EPA Reach File Version 3 (RF3). These data covered the entire study area and was very accurate (USGS 1999a), however it was only available at 1:100,000 scale. These data were available for each eight digit CU directly from

the USGS and were accessed using the USGS's data viewer (a modified ArcView program). To be used outside this data viewer, each CU had to be opened in the data viewer, the additional data tables with feature descriptions were joined to the attribute table of the required theme (each CU has themes for drainage as well as polygonal, line, and point features), and then the theme was saved as a new shape file that was used in ArcView.

Hydrography data (both linear and polygonal) were also used from the Georgia GIS Clearinghouse. These data were created by the Georgia Department of Transportation (DOT) by scanning the USGS 7.5 minute Blue Layer Mylar Separates and then editing them manually in ArcInfo (GA DOT 1996). They were 1:24,000 scale data and provided more information on small, first order streams missing from the NHD. Because these data did not cover the entire study area, data were still needed for areas across the state border in North Carolina, Tennessee, Alabama, and Florida. For almost all of the border areas, except a few spots in Florida and Tennessee, 1:24,000 DLG hydrographic layers were available in 7.5 minute quadrants through either the USGS directly or through the GIS Data Depot. The DLGs from both sources were only available in (SDTS) format and were converted into ArcView coverages using the tortuous set of actions laid out by US Fish and Wildlife Service (USFWS) (USFWS, 2000). Once in ArcView, these coverages were edited to eliminate any overlap, unprojected, and then merged with the data produced by the DOT to create a single theme for the entire study area at 1:24,000 scale. This was also done to create a theme for polygonal hydrography. As a last resort, for those quadrants

not covered by DLGs, the 1:24,000 Digital Raster Graphics (DRGs) were obtained from the GIS Data Depot. The DRGs were geo-referenced digitized versions of the USGS's topographic maps. These were then used to complete the hydrography theme using heads up digitizing. Because the map is digitized, it can be recolored turning all of the colors to white except blue, allowing for rapid tracing of each stream.

Another difficulty arose because the data from the two sources did not always agree. This was especially true for stream names in the attribute data and, on rare occasions, the location of streams. For all purposes, the National Hydrography Dataset was used primarily, except for when it provided no data (i.e. did not show a stream, or did show a stream, but did not give a name).

Land cover data provided most of the information that was used to determine the amount of impact found in both catchments and riparian zones. A draft version of the product of the Multi-Resolution Land-Characteristics Consortium (MRLC) was provided by Jim Harrison of EPA Region 4 (USGS 1999b). These data have since been published as the National Land-Cover Data, 1992 (NLCD92) (Vogelmann et al. 2001). These data were produced by analyzing two sets of Landsat 5 Thematic Mapper satellite data (leaves on and leaves off), collected between 1991 and 1993. Landsat measures the spectral signature (in multiple bands/wavelengths) of each 30-m x 30-m pixel, which is then run through an unsupervised clustering algorithm that produces a set of pixels with similar spectral qualities. These pixels are then related to a type of land-use found on the ground at that location (determined by a combination of ground

truthing and aerial photo interpretation). These interpreted data were then combined with other ancillary data (topography, census, agricultural statistics, soil characteristics, other land cover maps, and wetlands data) and logical modeling to place each pixel into one of 21 different land-use classes based on the Anderson Level II classifications(see table 2-2, Modified Anderson Level II Land-use classifications used in NLCD92). Accuracy of the data was assessed at randomly chosen pixels and groups of pixels by comparing the classifications assigned in the NLCD to those determined by photo interpretation. For EPA Region 4 the overall accuracy was 81% for the level II classifications, with the urban classes being the least accurate (down to 23% for commercial/industrial), and the forest classes being the most accurate (up to 100% for mixed forest). Since many of the errors occurred within an Anderson Level I classification (i.e. confusing pasture with row crops and vice a versa), accuracy improved to 83% when comparing urban vs. agricultural vs. forested. (Vogelmann et al. 2001, USGS 2001a) Unfortunately, this accuracy assessment was also in doubt, since the classifications by photo interpretation were not without error, and the photos that were used were two years older than the satellite data, so some of the land uses may have changed in the interim. My own accuracy assessment of these data based on the comparison of NLCD92 to areas of known land use in Georgia agrees with this assessment. The NLCD92 data were correct in all cases except in one low intensity residential area (with many large older trees), where approximately a third of the area was classified as mixed forest. I expected that errors of this sort may have been common across the state, but occurred

Table 2-2. Modified Anderson Level II Land-use classifications used in NLCD92.

Category	Code	Description
Water	11	Open Water
	12	Perennial Ice/Snow
Developed	21	Low Intensity Residential, 30-80 percent of cover is man made, single-family housing
	22	High Intensity Residential, 80 to100 percent of cover is man made, apartment complexes
	23	Commercial/Industrial/Transportation
Barren	31	Bare Rock/Sand/Clay, Perennially barren areas of bedrock, scarps, talus, slides
	32	Quarries/Strip Mines/Gravel Pits
	33	Transitional Forested Upland, sparse vegetative cover, includes forest clearcuts
Forested Upland	41	Deciduous Forest, 75 percent or more of the tree species shed foliage
	42	Evergreen Forest, 75 percent or more of the tree species maintain their leaves all year
	43	Mixed Forest, neither deciduous nor evergreen species represent more than 75 percent
Shrubland	51	Shrubland, shrub canopy accounts for 25-100 percent of the cover
Non-Natural Woody	61	Orchards/Vineyards/Other
Herbaceous Upland Natural/Semi-natural Vegetation	71	Grasslands/Herbaceous, not intensively managed, but are utilized for grazing
Herbaceous Planted/Cultivated	81	Pasture/Hay
	82	Row Crops, such as corn, soybeans, vegetables, tobacco, and cotton
	83	Small Grains, such as wheat, barley, oats, rice
	84	Fallow
	85	Urban/Recreational Grasses, includes parks, lawns, and golf courses
Wetlands	91	Woody Wetlands
	92	Emergent Herbaceous Wetlands

proportionally to the amount of urban area present, so that measures of relative land use remained accurate, even if absolute measures of land use did not.

Another measure of the amount of human impact on a catchment is the road density in the catchment. The ideal data set to do this with would have been the transportation 1:24,000 scale DLGs produced by the USGS. These would have all the roads in each catchment and include the type of road surface in the attributes. Unfortunately, these were only available at that time for a limited number of quadrangles in Georgia (As the USGS updates each quadrangle, they are producing and making available the DLGs used to produce the maps). The Georgia DOT has produced a 1:24,000 scale statewide dataset of all public roads based on the DOT's general highway base map, which has been revised using 1993 Digital Ortho-Photo Quarter Quads (DOQQs). This dataset was not independently assessed for accuracy, although the DOT did perform internal quality control (GA DOT 1997). These data did not cover any parts of the study area outside of Georgia nor did it cover the road networks found on the two large military posts in the state, Ft Benning and Ft Stewart. These gaps in coverage were fixed using the same method used to supplement the hydrographic data described earlier.

To make the amount of road data between the two sources equivalent (the DLGs had many private roads, dirt roads, and trails that were not in the DOT data), overlapping areas between the DLG and the DOT data were examined before they were edited out. Using the "select by theme" function in ArcView those features found in DLGs, but not in the DOT data, were selected. Then, by seeing which road classes represented the majority, these classes could be excluded before combining the datasets. So for the area along the Tennessee -

Georgia border, roads of class III and higher were selected to be merged with the DOT data to produce a single theme for the entire study area. The area along the Florida – Georgia border included roads of class IV and higher, presumably because of the higher proportion of unpaved public roads in that region.

Since catchment wide land-use was not necessarily correlated with the occurrence of point sources of pollution, data on these point sources was also needed to ensure they were excluded as possible reference sites. The EPA has produced a nationwide set of data and a set of GIS analysis tools designed to be used with these data in the Better Assessment Science Integrating point and Nonpoint Sources (BASINS) program. These data were again organized by CU, but unlike the NHD, these data were already in ArcView format and could be used directly. The data available for point sources included the EPA's Office of Water (EPA/OW) Industrial Facilities Discharge (IFD) database for CONUS (USEPA 1998a), EPA/OW Permit Compliance System (PCS) for CONUS (a national computerized management information system that automates entry, updating, and retrieval of National Pollutant Discharge Elimination System (NPDES) data) (USEPA 1998b), and USEPA Toxic Release Inventory (TRI) of industrial manufacturing facilities in the United States (USEPA 1998c). The accuracy of the data in each of these datasets was assessed by comparing the location information (latitude & longitude) to other positional data for the facility in the same data set (state for PCS, county for IFD, or zip code for TRI). Any facilities without agreement between the positional data were excluded from the dataset (EPA 1998a, 1998b, 1998c).

Additional data were used in locating or providing context for the data described above. These included boundaries for states and counties, military posts, 7.5 minute quadrants, hydrographic Cataloging Units, and nature reserves.

As sources of comparison for the evaluation of my reference sites, three sets of previously identified candidate reference sites were provided by Georgia Department of Natural Resources, Environmental Protection Division (EPD). One set was of 35 sites selected using best professional judgment by Dr. Hoke Howard of the USEPA Region 4 Science & Ecosystems Support Division. These were provided as a list of stream names with latitudes and longitudes, which were imported into ArcView by creating a "point event" theme based on the coordinates. The next set was 19 sites selected by best professional judgment by Becky Blasius, an aquatic entomologist working for EPD. Eleven of these 19 sites were already listed by Dr. Howard, leaving only eight additional sites identified. These sites were provided by name, road junction, and Georgia Gazetteer (DeLorme Publishing Company 1998) page number. They were imported into ArcView by superimposing the previously created event theme over 1:100,000 scale Digital Raster Graphics (DRGs) of the entire state. The appropriate road/stream crossing was located on the DRG, and then a point was added to the event theme for each site. The third set consisted of 70 sites, of which 35 were also on Dr. Howard's list, Ms. Blasius' list, or both. The origin of this list of sites is a bit of a mystery, since no author is listed and my inquiries to EPD as to the origins of the list were unanswered. However, comments included

about different sites indicated that the list is probably a compilation of sites chosen by different programs, intuitions, and individuals using different methods. These sites include ones apparently recommended by the Wildlife Resources Division of GA DNR based on fish Index of Biological Integrity (IBI) data, reference sites used by the EPA's Regional Environmental Monitoring and Assessment Program (REMAP), sites recommended by Dr. Judy Meyer of the University of Georgia, and sites recommended by Dr. Howard. The location of these sites was provided by a combination of latitudes and longitudes, stream/road crossings, stream name with county or city, or in one instance, only a stream name. The 35 sites in addition to the ones from the other lists were added to the theme created earlier using a combination of the methods used on the previous lists.

Data Analysis.

The steps I used to choose candidate reference sites were: (1) delineating areas to be compared, (2) measuring the amount of land use impact in each of those areas, and then (3) choosing the least impacted sites to be candidates. The first step, delineating areas, was necessary to make it practical to solve this problem. Although a continuous measurement of each stream's impact may be possible, it would require greatly increased amounts of time and computing power. In order to develop a method that was of practical use by organizations with access to only desktop PCs, the simplification of utilizing specified areas was necessary.

Because stream biota varies longitudinally, any system of comparing streams will have to account for this natural variation (Stanford 1996; Allen 1997). In this study, I wanted to control for this variation by studying a single size class of stream catchments. Often in the past, stream order was used to describe relative stream size (Allen 1997) and I initially used stream order to delineate study catchments. Stream ordering was done using the Strahler stream ordering method (Leopold et al. 1992). In choosing which size stream to focus upon, a balance was struck between using catchments that were small enough to fit within sub-ecoregions and have wadable streams and catchments that were large enough to have perennial streams that would be flowing, even during drought conditions. Fourth order streams were chosen as an appropriate size to study. Fourth order streams are relatively common even in the smallest sub-ecoregions, and local fourth order streams were found to still be flowing in spite of the drought. In addition, large second and third order streams with a total catchment length of more than eight kilometers and small fifth order streams with catchment lengths of less than eight kilometer were also included, since they had roughly the same catchment area as most fourth order catchments.

Before selecting stream catchments for delineation, all of the stream orders for a specific area had to be determined, and several interim products had to be produced. First, a small enough area to be workable in terms of processing time and output size had to be chosen. A single CU or sub-ecoregion was usually chosen as a work area. The extent of analysis was limited by modifying the view using the zoom and pan controls until just the area of interest was shown on the

display, then setting analysis properties to "display extent". This would limit the subsequent analysis, and the products produced, to this area. The script, "PDNP Stream Ordering", was then run using both of the hydrographic themes and the corrected DEM theme. I wrote this script to produce a stream order theme based on a combination of two hydrographic datasets (see appendix B). This script also produced a grid of flow direction based on the DEM, showing which cell flow would go to based on the which neighboring cell had the steepest drop in elevation, and a grid of flow accumulation which would be used to delineate catchments.

With the stream order theme laid over the sub-ecoregion of interest and the stream orders of interest highlighted, stream selection and catchment delineation began. The "Catchment Point" script was used to do the catchment delineation. It works by the user selecting a cell from the DEM to function as a "pour point" for the catchment to be delineated. ArcView then selected every other cell that produced flow that eventually went through this pour point based on the flow direction grid created earlier. All of these cells were then used to create a new polygon that was then added to the view. The selection of the pour point was done "semi manually" (semi, because the script would actually select the cell with the highest flow accumulation within a set distance of 240 m of the point selected by the operator). The pour point was then chosen to be either at the next stream confluence or where the stream would leave a sub-ecoregion. Since these data did not account for impoundments, actual impoundment data in the form of polygonal hydrography had to be included in the decision on where to define

catchments from. When pour points were chosen, if an in-stream impoundment existed immediately upstream, or one downstream caused that pour point to be inundated, then a pour point was selected up-steam of the impoundment if it still provided an overall catchment length of over eight kilometers.

Since I was using an ecoregional framework to delineate candidate catchments, the dilemma arose about what to do with those catchments that lay in multiple sub-ecoregions since sub-ecoregion boundaries do not generally coincide with catchment boundaries. The simplest solution for those streams that reached the required size before crossing the ecoregion boundary was to delineate the catchment at or near that boundary. Streams that were divided into different regions longitudinally, or had their headwaters in one sub-ecoregion but did not become large enough to be considered a possible site presented a more complex dilemma. Different solutions to this dilemma have been proposed. Gibson et al. (1996) recommended that candidate sites lie entirely within a single ecoregion. Warry and Hanau (1993) used sites with at least 50% of the catchment within a single ecoregion. Omernik (1995) recommended using sets of catchments with similar proportions of different ecoregions. The decision to combine some of the small, linear sub-ecoregions functionally created a group of streams composed of the same two sub-ecoregions in similar proportions. However, developing groupings of catchments for each adjacent pair of sub-ecoregions would have been cumbersome (producing an additional 33 groups), and impractical, since many, if not all, of the groups would have been too small for meaningful comparisons of impairment within the group. Since sub-ecoregion

boundaries do not usually represent a demarcation between one area and another, as much as the center of an ecotonal zone between areas (Bryce and Clarke 1996), rejecting streams that did not lie entirely within single sub-ecoregion was regarded as too harsh a criterion. These ecotonal zones between regions vary in width, anywhere between 3 to 75 km, so any catchment near the boundary will have some of the characteristics of the neighboring region (Gallant et al. 1989). A catchment should be delineated so that it has more characteristics in common with the catchments of its sub-ecoregion, than of its neighboring region. A criterion of 50% of a catchment in a single sub-ecoregion would not provide this. Since I was interested in choosing catchments that would represent sub-ecoregions, I decided not to delineate those catchments that did not have at least approximately 80% of the catchment within a single sub-ecoregion. This was an arbitrary criterion for delineation, but one that retained catchments that represented the entire span of variation found in each sub-ecoregion, while eliminating those catchments that did not clearly have the majority of the characteristics of one sub-ecoregion or another.

Hughes et al. (1986) recommended selecting candidate catchments based on catchment area and annual discharge as opposed to stream order. They also recommended that the sites to be compared differ by less than an order of magnitude. Based on these recommendations, the delineated catchments were reassessed. Using the Analytical Tools Interface for Landscape Assessments (ATtILA) ArcView extension (see details below), areas for all of the delineated catchments were calculated. The range of areas for each sub-ecoregion was

examined to ensure that all the catchments were within a single order of magnitude. Catchments that were too large were either split into smaller catchments or simply redelineated with the pour point of the catchment moved upstream. In some cases, catchments that were too small were combined to form larger catchments. Although some size variation was allowed between sub-ecoregions (table 2-3), catchment size statewide was generally between 10 and 100 km^2.

The catchment boundaries developed this way were usually within 10 to 20 m of the actual drainage divide determined from USGS topographic maps. Boundaries for adjoining catchments also showed good agreement, usually being within 10 m of each other. One artifact of using the DEM grid to delineate catchments did need correcting. If a catchment had an outlying grid square, one that was connected to the rest of the catchment at only one corner, then when the polygon was created from this grid, the outlying square was represented by an adjoining, but separate polygon. Since subsequent analysis was going to be done on each polygon, the polygon theme had to be edited to remove these extra polygons. Usually in editing, the extra polygons were simply deleted, but if they appeared to represent a significant area (greater than 0.5 ha), they were joined with the main polygon representing the catchment. All of the catchments in a sub-ecoregion were then combined into a single theme, with the area calculated for each one, and a unique catchment code assigned. The catchment code was the sub-ecoregion code combined with a unique number for the catchment within its sub-ecoregion, generally being numbered from left to right,

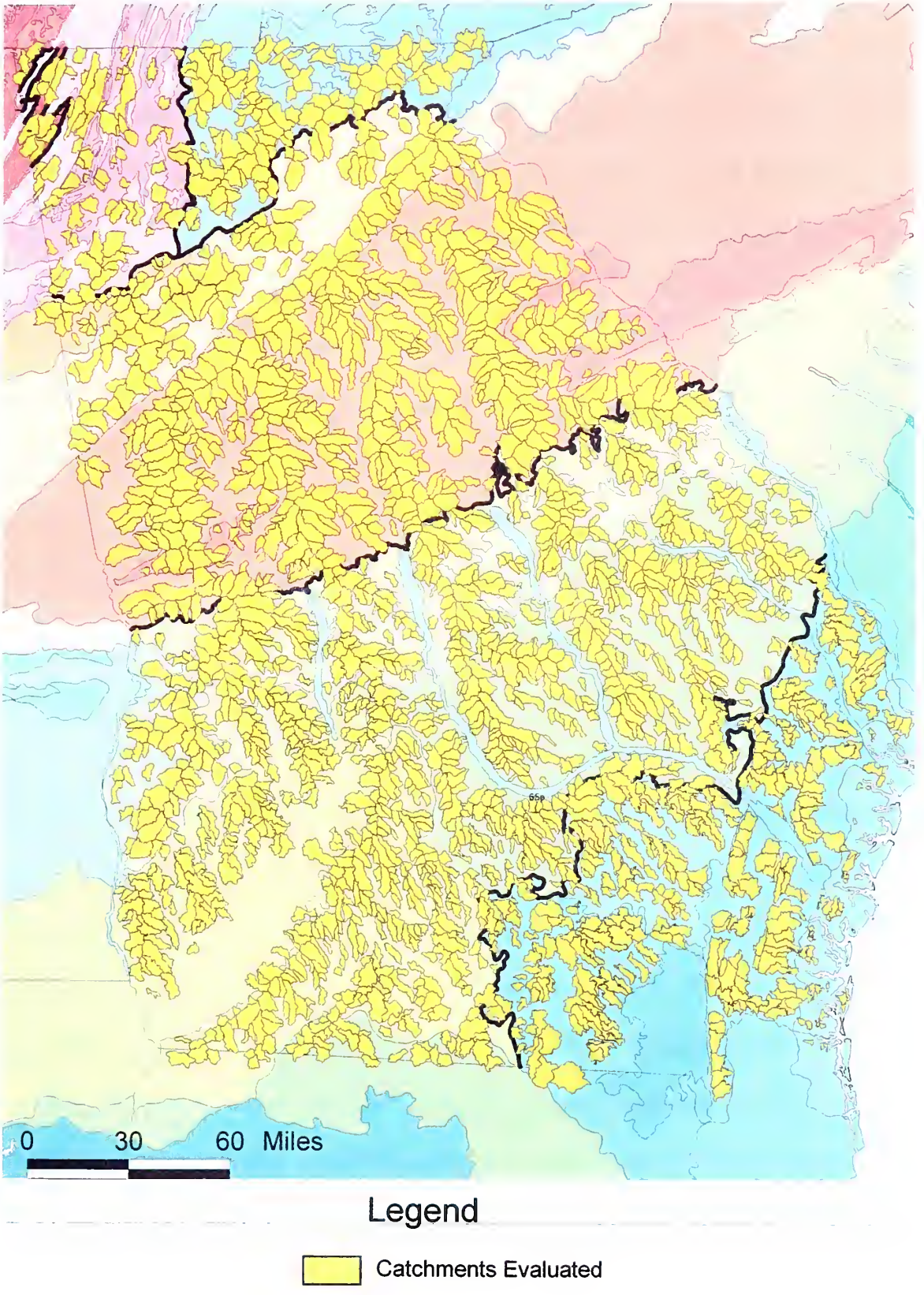
top to bottom (i.e. catchment "65o-01" was the northwestern most catchment delineated in sub-ecoregion 65o). The final product of the delineation of catchments was a total of 2158 catchments within the study area as shown in figure 2-3, Catchments Evaluated (see also table 2-3, Evaluated Catchments Statistics by Sub-ecoregion). These catchments were then joined into a single theme for each sub-ecoregion for subsequent land-use measurements.

The next step was to measure the relative amounts of human impact on each catchment. Each of these measurements were made using an extension for ArcView developed by Donald Ebert & Timothy Wade of EPA's Landscape Ecology Branch (part of the Office of Research and Development's National Exposure Laboratory, Environmental Science Division) called the Analytical Tools Interface for Landscape Assessments (ATtILA) (Ebert and Wade 1999). ATtILA was designed specifically to analyze landscape data, including the NLCD 92, in terms of discrete areas such as polygon themes of counties, ecoregions, or catchments. Input was provided as themes of land use data and the resulting output data were appended to the attribute table of the polygonal area theme you were analyzing. Inputs used included a theme of all the delineated catchments in sub-ecoregion, a raster land-use theme (NLCD 92), hydrography data (GA DOT data), and road data (GA DOT data). The "landscape characteristics" function then determined the total area and percentage of cover for each of the major land-use categories (see table 2-2, Modified Anderson Level II Land-use classifications used in NLCD92) within each catchment. Since silviculture represented one of the larger (if not the largest) form of human impact on

Table 2-3. Evaluated catchments statistics by ecoregion and sub-ecoregion.

Ecoregion / Sub-ecoregion	# of Catchments	Catchment Area (km^2)			Agriculture		Barren		Urban	
		Mean	Minimum	Maximum	Maximum %	Minimum %	Maximum %	Minimum %	Maximum %	Minimum %
Piedmont Ecoregion 45										
45a	91	63	18	142	47.4	1.4	9.7	0.0	52.3	0.1
45b	408	52	13	130	60.1	0.0	23.5	0.0	67.9	0.0
45c	21	37	11	105	38.1	1.6	15.5	0.1	1.3	0.0
45d	23	26	8	62	16.5	0.6	32.9	0.0	7.1	0.0
45h	16	29	8	77	21.1	0.7	10.4	0.0	8.4	0.0
45	559	41	8	142	60.1	0.0	32.9	0.0	67.9	0.0
Southeastern Plains Ecoregion 65										
65c	92	41	11	120	62.9	0.3	32.7	0.0	57.8	0.0
65e	39	42	12	101	31.2	0.3	16.3	0.0	72.3	0.0
65g	137	32	9	90	85.9	11.7	12.4	0.9	15.2	0.0
65h	211	29	10	102	75.1	5.4	31.8	0.8	74.5	0.0
65k	143	31	8	80	86.2	0.2	42.6	0.0	22.0	0.0
65l	409	30	10	96	85.2	4.1	40.6	0.3	20.5	0.0
65o	28	33	10	78	38.6	1.6	21.9	5.2	16.4	0.0
65	1059	34	8	120	86.2	0.2	42.6	0.0	74.5	0.0
Blueridge Ecoregion 66										
66d	32	51	17	119	7.5	0.0	1.2	0.0	1.4	0.0
66g	68	41	12	113	21.6	0.0	18.5	0.0	5.8	0.0
66j	12	37	20	84	13.7	2.8	2.6	0.0	1.2	0.0
66	112	43	12	119	21.6	0.0	18.5	0.0	5.8	0.0
Ridge & Valley And Cumberland Plateau Ecoregions 67 & 68										
67f&i	42	46	12	125	51.3	6.1	11.0	0.0	38.1	0.0
67g	24	30	7	64	27.5	0.8	14.5	0.0	4.9	0.0
67h	9	10	4	26	14.9	0.1	13.7	0.0	0.0	0.0
68c&d	10	41	18	75	25.1	2.6	4.0	0.0	2.2	0.1
67 & 68	85	32	4	125	51.3	0.1	14.5	0.0	38.1	0.0
Coastal Plains Ecoregion 75										
75e	80	38	10	101	53.6	0.0	30.2	0.4	2.8	0.0
75f	147	38	10	107	45.1	0.0	31.6	1.4	62.8	0.0
75h	73	37	11	108	60.3	1.0	17.7	1.7	45.5	0.0
75j	43	10	4	33	23.8	0.0	17.2	0.0	61.5	0.0
75	343	31	4	108	60.3	0.0	31.6	0.0	62.8	0.0
Georgia	2158	36	4	142	86.2	0.0	42.6	0.0	74.5	0.0

Figure 2-3. Catchments evaluated as possible candidate reference sites.



landscapes in Georgia, it was important to have some measurement of it for each catchment. Areas that had been categorized as barren/transitional (land-use code 33) include clear cuts, transitions between forest and agriculture, and areas disturbed temporarily by natural causes like fire or flood (USGS 2001b). Since the amount of agricultural land was relatively stable and the amount of land that is allowed to under go natural disturbances was small compared to the amount of land clear-cut in Georgia, it was assumed that all transitional areas were clear cuts. This assumption was supported by the often square or regular shape of transitional areas. The amount of clear cuts was then used as a surrogate for estimating the relative amount of silviculture within a catchment.

The "riparian characteristics" function was used to calculate total areas and percentages of land-use for three buffers of different width along all the streams within a catchment. These buffers are created in terms of numbers of pixels from the stream, so buffer distances are a function of pixel size. The smallest buffer was made up of the pixels that have the stream flowing through them. For practical purposes, this approximated a 10 to 15 m buffer (based on the simplifying assumption that the stream was flowing through the center of a 30-m x 30-m pixel). Buffers were also calculated at one and four pixel distances, providing buffers with widths of 40 to 45 m and 130 to 135 m respectively.

The "human stresses" function was used to measure road density and the number of stream/road crossings within a catchment. Road density was calculated as the total road distance (in kilometers) within a catchment divided by the area of the catchment (in square kilometers). Stream crossings by roads

were calculated both as a number and as a density (number of crossings per kilometer of stream). This function was also used to calculate stream density. Although this does not function as a measure of impact, it was used to ensure that each catchment was representative of its sub-ecoregion.

I used the "beta" version of ATtILA to perform the calculations described above. All of these functions seemed to be preformed flawlessly. ATtILA is capable of many other functions that may have had applicability to this project, including calculating population density based on census data, calculating stream slope based on DEM data, catchment precipitation and elevation statistics, and the total road length within a defined distance of any stream. I did not use these other analyses either because I did not have the necessary data (census, precipitation) or the function did not perform as expected (roads within given distance, stream slope).

In addition to the impacts that were measured as described above, some measure of disruption of hydrology in each catchment was desired. I considered the most effective measurement for Georgia to be the measurement of impoundment density because of the availability of data on impoundments and the amount of hydrologic impact they created relative to other human disturbances like channelization. Surface water withdrawals would also have made a good measurement of disturbance, but Georgia lacked a readily available dataset describing withdrawals geographically. Because natural lakes occur very rarely in Georgia, except in the most southern physiographic regions (Wharton 1978), one can assume for most of the state that all lakes and ponds,

indeed any polygonal water feature that is not a wetland, is the result of an impoundment. So, while specific data on impoundments exists for only the largest of the state's impoundments, the polygonal hydrography themes from both the NHD and the GA DOT could be used as indirect measures of impoundment density. Indeed, another study of the effects of impoundments on streams in Georgia that was underway concurrently with this study independently came to the same conclusion (Merrill et al. 2001). Naturally occurring sinkhole lakes across the southern part of the state confounded this simplifying assumption. However, if one also assumes that sinkhole lakes were randomly or uniformly distributed across a sub-ecoregion, then the density of sinkhole lakes should have been roughly the same for each catchment within the sub-ecoregion, so differences in the calculated lake densities were then attributed to manmade impoundments.

Measurements of impoundment density were made using the more detailed GA DOT hydrography dataset. With a single catchment selected from the set of catchments for a sub-ecoregion, the "select by theme" function was used to select all of the features of the polygonal hydrography data that had their centers in the selected catchment. This ignored off-stream impoundments that merely overlapped the catchment, and did not actually fall within it. The attribute table for the polygonal hydrography was opened and the statistics function was run on the area field providing a sum of all of the areas for the selected records. This represented the total area of all polygons within the selected catchment. This number was then copied into a record of the previously added impoundment area

field in the attribute table of the sub-ecoregion's catchment theme, as well as the number of selected records, recording the number of different impoundments present in the catchment. Once the total impoundment area had been calculated for each catchment in the sub-ecoregion, another field was then created and filled using the calculation function, dividing each total impoundment area by the catchment's area to yield impoundment density.

To speed up the processing of data, I decided to wait until after candidate reference sites were chosen from the land-use data before assessing the impacts from point sources. This way only a small number of catchments needed to be assessed, and they could be replaced or disregarded as appropriate.

The attribute tables for the catchments, with the amounts of human impact on each catchment, were then converted from their database format (D-Base4) into Microsoft Excel format. The types of measurements made are summarized in table 2-4.

The next step was to decide which catchments were the least impacted based on the measurements made. An iterative approach was used to develop a selection method, starting by analyzing the results of possible methods against the raw data, then by comparing predictions against a sample of ground truthed streams, and finally to a validation of the method in several different sub-ecoregions. I initially tried an approach based on filtering out catchments that did not meet some minimum criteria. Dr. Michael Barbour of Tetra Tech Inc. provided me with some recommendations on possible criteria that had been

Table 2-4. Summary of land-use measurements made.

Measurement	Catchment wide	15m Riparian Buffer	45m Riparian Buffer	135m Riparian Buffer	Made by	Source data
% Natural Cover	X	X	X	X	ATtILA	NLCD92
% Urban	X	X	X	X	ATtILA	NLCD92
% Total Agriculture	X	X	X	X	ATtILA	NLCD92
% Row Crops	X	X	X	X	ATtILA	NLCD92
% Pasture	X	X	X	X	ATtILA	NLCD92
% Barren	X	X	X	X	ATtILA	NLCD92
% Forest	X	X	X	X	ATtILA	NLCD92
% Wetland	X	X	X	X	ATtILA	NLCD92
Road Density	X				ATtILA	GA DOT
Density of Road/Stream Crossings	X				ATtILA	GA DOT
# of Road/Steam Crossings	X				ATtILA	GA DOT
Impoundment Density	X				Manual Analysis	GA DOT
# of Impoundments	X				Manual Analysis	GA DOT

developed as an agreement between several southeastern state environmental agencies in 1998. These criteria are presented in table 2-5, land use filters from 1998 inter-state agreement, and are similar to land-use criteria developed by the state of Maryland presented in table 1-2. These criteria were applied to the land-use measurements that I had made, but these criteria did not perform well as a way of selecting the least impacted catchments. More than 50% of available

Table 2-5. Land use filters from 1998 inter state agreement.

Filter	Criteria
Natural Land cover	> 65%
Agriculture Land cover	< 20%
Urban Land cover	< 15%

catchments were selected as possible candidate reference sites in all the areas of the state except in four sub-ecoregions of the Southeastern Plains ecoregion. Because of the wide variety of types and amounts of impairment among sub-ecoregions in Georgia, to make a filtering system to work a specific filter would be needed for each sub-ecoregion. On the recommendation of Dr. Barbour, I was also concurrently trying to develop a criterion for road density, since it had been shown to correlate with aquatic integrity. I had begun ranking sites that had met all criteria by their road density, so that those catchments that met all of the criteria and had the lowest road density would receive the best ranking. Since filtering did not appear to be a reasonable way of selecting the least impacted sites, I decided to attempt to rank all the catchments for multiple impacts. The least impacted sites could then be simply chosen from the top of the list.

The initial attempt at ranking was done by assessing a single impact measurement at a time, and then ranking all catchments based on that measurement. A combined ranking for all measurements was then produced by summing each of these individual rankings for each type of impact for each catchment. The catchment with the lowest combined ranking was considered the best. A comparison of these results against the raw data showed that this method did not give the least impacted catchments (in terms of total amount of impact) the best scores, because simple ranking did not account for the distribution and the negative correlation between different impacts. Generally, urban land use has a highly aggregated distribution, so it is usually less than one

percent of a catchments land-use, unless it is in an urban center where it can become quite high. Therefore, catchments may receive relatively high (poor) rankings even if they were not significantly impacted compared to the best catchments, but were considerably better than the worst catchments. An example of this can be seen in the data for sub-ecoregion 45d, the Talladega Upland Sub-ecoregion (see figure 2-1, draft level IV sub-ecoregions of Georgia). Here the best ranking catchment and the 20th ranked catchment had relatively similar amounts of urban land-use (0% and 0.5% respectively), but the 20th ranked catchment had a rank much closer to the worst catchment (with a rank of 23rd) which has an urban land-use of 7.1%. Many land-uses are also negatively correlated with one another, such as the low levels of agricultural land-use found in areas of high urban land-use. This effect combined with the skewness of different land-use distributions to make simple combined rankings useless. As a hypothetical example, take a catchment that had the fifth lowest land-use measurement for 10 different measures. It would receive a combined rank of 50 (5^{th} ranked x 10 measures), but may have individual land-use measurements that were not much different from the best available in that sub-ecoregion. Another catchment that is entirely dominated by a single type of land-use, like urbanization, may have the best ranking for nine measurements and the worst ranking on one measurement and receive a combined rank of 29 (1^{st} ranked x 9 measures + 20^{th} ranked x 1 measure).

Another scoring system was attempted to overcome the deficiencies of simple combined ranking. Scores were assigned based on which quartile the catchment

fell into for a particular measurement, to account for the aggregate distribution of the data, ranging between one and four. Catchments that had measurements in the lowest quartile would receive a value of one, while those in the highest quartile would receive a four. These scores would then be summed for all measurements and the lowest scoring catchments would be selected as candidate reference sites. So for our hypothetical example above, the first catchment would receive a score of 10 (lowest quartile = 1 x 10 measurements), while the second catchment would receive a 13 (lowest quartile = 1 x 9 measurements + highest quartile = 4 x 1 measurement).

Another question that was addressed at this time was the determination of which measurements to use and how they should be weighted. Table 2-4 shows the 37 measurements made on each catchment, consisting of 13 catchment wide measurements and 24 riparian measurements. Although the relative importance of riparian impacts versus catchment wide impacts is still being debated, it is generally agreed that both play an important role in determining the integrity of the stream ecosystem (Hunsacker and Levine 1995; Allen et al. 1997; Richards et al. 1997). Since each measurement provides an equal amount of input (each one gets one vote), having more riparian measurements unintentionally weighted the resulting composite score. Also, impacts that had both simple and derived measurements (e.g. the number of impoundments versus impoundment density), in effect, were counted twice. Those impacts that were measured as components and as a total impact (row crop, pasture, and total agriculture) were also over-represented. Therefore, from the entire list of measurements made, a

sub-set of nine measurements were chosen for use in selecting reference sites (table 2-6, land-use measures used in selecting candidate reference sites).

Table 2-6. Land-use measures used in selecting candidate reference sites.

Primary Selection Measures	
Catchment Wide	% Urban
	% Total Agriculture
	% Barren
	Road Density
	Density of Road/Stream Crossings
	Impoundment Density
15 m Riparian Buffer	% Urban
	% Total Agriculture
	% Barren
Tie Breaking Selection Measures	
45 m Riparian Buffer	% Urban
	% Total Agriculture
	% Barren
135 m Riparian Buffer	% Urban
	% Total Agriculture
	% Barren

This scoring system also tended to produce many tie scores because of its relatively low number of possible scores (27). This became a problem when it came time to select the top five catchments as candidates and several catchments were tied for fifth place. I decided to use the riparian data that were not used for initially scoring catchments (data for the 45 m and 135 m buffers) to break ties. These data were scored as the other measurements were scored and then combined with all the original scores to produce a larger compound score. If this larger score failed to resolve a tie, then the total percentage of land in non-

anthropogenic use (a combination of all forest, wetland, and shrubland) was used to break the deadlock.

Since this selection method worked well when comparing the results to the raw data, it was then compared to actual streams to see how well it predicted relative amounts of impact. Sub-ecoregion 45h, the Pine Mountain Sub-ecoregion, was chosen as the area to test these predictions because of its relatively small size (composed of only 16 catchments) and its proximity to Columbus. Ten sites were visited, focusing on those predicted to be the least impacted, and their habitat quality was assessed using the Habitat Assessment Form found in the EPA's Rapid Bioassessment Protocol (see appendix C) (CSU 2000). These assessments judged habitat quality on a 20 point scale, and were supplemented with visual assessments on a 10 point scale of the water quality, human impacts, and substrate (see table 2-7, visual habitat assessments). These supplemental assessments gave a qualitative measurement of some of the variables normally measured quantitatively in the RBP process. Using this supplemented RPB assessment methodology allowed rapid assessments of the relative quality of these streams when compared among themselves since they were all observed by the same people on the same day. Assessments were generally made directly upstream of the closest road crossing to the bottom of the catchment by a consensus of the two people assessing the stream. Additional notes on observed fauna, local land-use, degree of shading, and accessibility were also made.

Table 2-7. Visual habitat assessments. These are the measures used to determine the relative quality of potential sites during method development.

Habitat Parameter	Description	Point Scale	Source
Epifaunal Substrate	Measure of diversity, amount, and stability of substrate	20	Apr 2000 RBP
Riffle Quality	Measure of riffle extent and substrate composition	20	Apr 2000 RBP
Embeddedness	Amount of fine sediment around gravel or cobble	20	Apr 2000 RBP
Sediment Deposition	Amount of deposition on bottom	20	Apr 2000 RBP
Frequency of Riffles/Bends	Ratio of distance between riffles/bends and stream width	20	Apr 2000 RBP
Channel Flow Status	Amount of substrate submerged	20	Apr 2000 RBP
Bank Vegetative Protection	Amount & diversity of vegetation	20	Apr 2000 RBP
Bank Stability	Evidence of active erosion	20	Apr 2000 RBP
Riparian Zone Width	Width of Riparian Zone	20	Apr 2000 RBP
Substrate	Measure of median size of substrate particles	10	John Olson
Water Quality	Measure of turbidity, and presence of oils/foam/algae/odor	10	John Olson
Impact Evidence	Evidence of trash, other deposits, silviculture, or grazing	10	John Olson

Of the ten sites visited, only three were clearly of reference quality. Of these three, only one had been predicted to be among the five best. A review of the data revealed that the two reference catchments had been excluded because of their poor scores for streams crossed by roads and impoundment densities.

To compensate for those catchments that had not been selected because of their scores for impoundment densities and stream/road crossings, I decided to change the relative weights of these scores. Although impoundments can cause

great disruption of a stream's hydrology, most of the impoundments were actually small in size (mostly farm ponds). Merrill et al. (2001) showed that for a portion of the Oconee watershed impoundments of less than 1ha were 72% of all impoundments, and that 98% of all catchments were less than 10 ha. These small impoundments, although causing some immediate loss of refugia, habitat, and longitudinal connectivity, probably had only minor impact on the water and habitat quality downstream. The streams crossed by roads measurements were similarly limited in their negative effects downstream. Road crossings affect streams during their construction, by constricting flow thus altering the hydrology, and as a source of sediment input (especially for dirt roads). Because the road data that was used from the GA DOT was primarily of long established paved roads, most of the effects of these crossings were minimized. Since the effects of impoundments and road crossings did not seem as great as the other types of impacts measured when assessed on the ground, I changed the weighting of both of these measurements from 1 to 0.5.

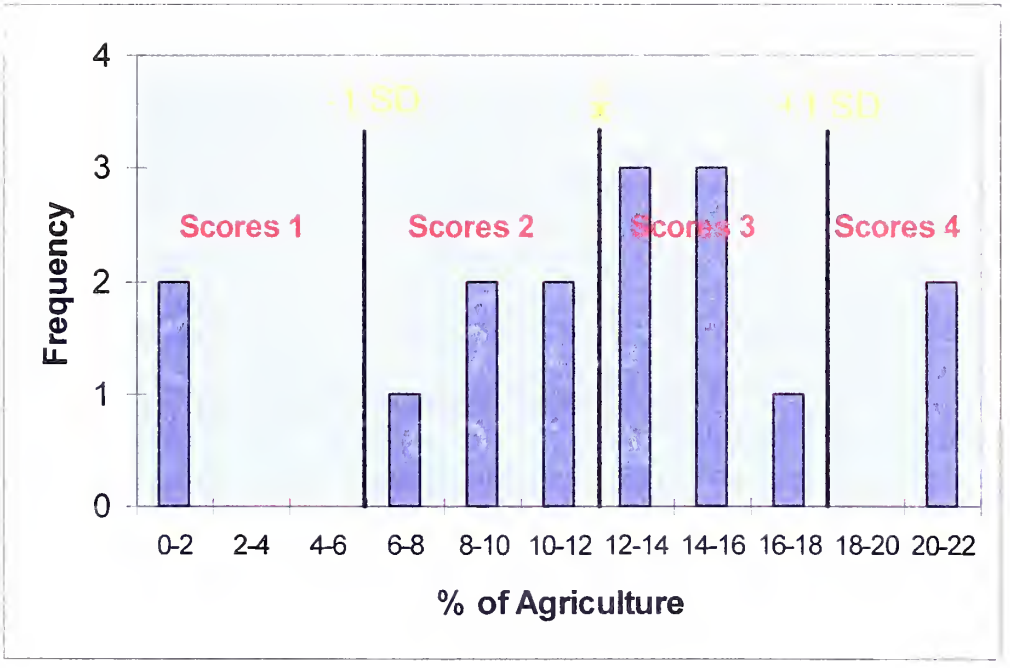
This new selection method was applied to the Pine Mountain data, and it selected the three sites we had deemed as reference quality. To validate this method it was then applied to another sub-ecoregion, 45d, the Talladega Upland (again chosen for its size and proximity). Thirteen of the 23 catchments in the region were evaluated, again focusing on what was predicted to be the least impacted. The stream ranking based on these assessments was then compared to the predicted ranking based on the quartile scoring method. The comparison between what the selection method predicted as the best sites and what was

actually observed showed that quartile scoring was still far from adequate, with only two of the predicted best five actually being one of the best five. Two of the predicted best five actually ended up having the lowest habitat quality of those we assessed on the ground (45d-16 & 22). Each of the individual quartile scores that had been given were again evaluated to see how well that score represented the amount of that impact in that catchment. This evaluation revealed that the arbitrary assignments of scores by quartile still did not adequately compensate for changes in distribution of impact. For areas with an impact that did not show much change between the first and second quartiles, such as areas with very low urbanization, or areas with wide spread agriculture, catchments may receive different scores (1 versus 2), but in fact are not significantly different.

In order to compensate for the changes in the distribution patterns of different impacts, a method of scoring that was based on the distribution was needed. I decided that basing a catchment's score for each impact on where it was in relationship to the mean might accomplish this. Those catchments that had measurements one standard deviation below the mean measurement for that impact in that sub-ecoregion received a score of one. Those that fell between one standard deviation and the mean received a score of two. Any that fell above the mean, but within a standard deviation received a three, while those that were a standard deviation above the mean received a four (see figure 2-4). This system, while still using somewhat arbitrary "bins" to assign scores, attempted to adapt to different distributions of impact found across the state.

This distribution-based method was then applied to the Talladega Upland and the results were assessed against what was already known about the

Figure 2-4. Assigning scores based on distribution. The histogram below shows the distribution of agricultural land use by catchment for the 16 catchments in sub-ecoregion 45h, Pine Mountain. Using the distribution based scoring system described in the text, the best two catchments received a score of 1, the worst two catchments received a score of 4, and the remainder received 2s and 3s.



catchments. While the two catchments with the worst habitat evaluations were still among the top five selected, the remaining three were all of reference quality, and those catchments with the best known habitat were among the top ten catchments predicted. The reason for one of the impacted catchments (45d-22) being predicted to be among the least impacted was readily apparent. While the data that was collected by satellite in 1993 had indicated that the catchment was 92% forest, when we arrived it had been almost entirely clear-cut. The other

impacted catchment offers no obvious explanation. Catchment 45d-16 appeared to have land-use patterns similar to what was measured in 1993. The downstream sites were mostly wetlands, which were not evaluated, while the upstream site that was evaluated was closer to most of the impact in the catchment. Obviously, predictions I was making were not always going to correlate to impact due to changes in land-use since the data collection, differences in land-use between where I evaluated a catchment (at a stream confluence) and where it could actually be accessed, and because the relationship of land-use to stream impairment was not always linear. However, the best available catchments were usually near the top of the list, so by assessing the best ten predicted catchments on the ground, the best five available catchments should be able to be located.

The distribution based selection method was then validated by using it to assess streams in 68c&d, 67f&i, 67h, and 67g. Using the same method used earlier, 39 of 85 streams in the area were assessed for habitat. Twenty of these streams were chosen to be candidate reference sites based upon site evaluations. Of these 20, all were in the top ten sites predicted by GIS for that sub-ecoregion and nine were in the top five. Although the method could have used further refinement, it did identify the least impacted sites available. I then decided that the method was good enough to be applied to the rest of the state to choose candidate reference sites.

Using the Microsoft Excel spreadsheets of land use created for each of the sub-ecoregions, distributional scores were calculated for each measurement, and

then summed, and then the sites were sorted by these summed scores. The project director, Dr. Jim Gore, decided upon a goal of sampling five candidate reference sites in each sub-ecoregion, or five percent in the larger sub-ecoregions. With the spreadsheets already sorted by summed score, the possible candidate sites were easily selected by assigning grades of one to the top five or five percent to be our primary catchments to be ground truthed and sampled if relatively unimpaired. The next five or five percent were assigned a grade of two to serve as alternates for any of the primary sites that were inaccessible or impaired. With the remaining sites all given a grade of three, this spreadsheet was saved as a tab delineated text document, imported into ArcView as a table, and joined to the attribute table of each of the shape files created of all of the catchments of a sub-ecoregion. Those catchments with grades of one or two were selected, converted to a new shape file, and merged into a single theme of all candidate reference catchments and alternates. Using the three datasets of point sources of pollution (IFD, PCS, and TRI) and the "select by theme" function, any catchments that had point sources within their boundaries were selected. They were then eliminated from the theme of candidate reference sites and, if they were primary sites, the top scoring alternate site in that sub-ecoregion was "promoted" to a primary site. This final theme was overlaid on top of a 1:100,000 scale DRG and printed as a map for field teams to use in finding the reference sites.

The sites that had been selected by best professional judgment underwent an abbreviated version of the same process used to select sites by GIS.

Catchments were first delineated from the location of each site in the point theme created from the original lists. Catchments that had also been chosen by the GIS were eliminated and remaining catchments were evaluated to ensure they met the size standards for reference sites (within an order of magnitude of all of the sites for that sub-ecoregion) and were located at least 80% within a single sub-ecoregion. Land use measures were then made of each remaining catchment. These measurements were then compared to measurements of the catchments that had been selected as possible candidates by GIS. Those catchments that had less impact than the ones selected by GIS, replaced those they beat as primary sites. Those catchments that did not have less impact than those selected by GIS, but did have land use measurements below the mean for that sub-ecoregion were included as additional alternate sites. The rationale for this was that these sites had been visited and evaluated as reference sites by someone in the past, and should be discarded only if the land use data clearly indicated they were impaired.

Method Assessment.

As part of the Georgia Ecoregions Reference Sites Project to define the reference condition for wadable streams in Georgia and develop biocriteria, the physical, chemical and biological condition of 87 candidate reference sites across the state were characterized between 6 October, 2000 and 6 March, 2001. Characterizations were preformed using the following procedures, as described in Columbus State University's (CSU) Quality Assurance Project Plan (CSU 2000):

1. Benthic macroinvertebrates were collected using the Georgia DNR's 20 Jab Method (CSU 2000), with the macroinvertebrates being identified to the lowest practicable taxonomic level.
2. Water chemistry was measured for the parameters in table 2-8 (water chemistry parameters measured) both in situ using a Hydrolab H-20 probe and by taking water grab samples that were later tested in the lab.
3. The streams physical properties were recorded. These included a stream cross section, velocity, substrate size using a modified Wollman Pebble Count, and observations of degree of shading and presence of oils, impacting land uses, bank erosion, and types of deposits.
4. Habitat assessments were also completed for each site using the EPA's Rapid Bioassessment Protocol habitat assessment methods and forms.

The 87 sites sampled included 78 sites I chose based on the method described above (referred to henceforth as GIS sites) and nine sites chosen by best professional judgment (referred to as BPJ sites). Both GIS and BPJ sites were subjectively evaluated by field crews prior to sampling to ensure sampling effort went to the best available sites. Four to five sites were sampled in each sub-ecoregion, except those severely affected by drought.

For this method of selecting candidate reference sites to be considered a success, it should be demonstrated that it does yield sites that adequately characterize the reference condition. Unfortunately, to know if the sites actually meet the standard of being the least impacted sites, we needed to know how impaired all of the available streams were. Since this was not going to be

Table 2-8. Water chemistry parameters measured at sites to determine water quality.

Parameter Measured	Type of Sample Taken	Method / Instrumentation Used	Range of Detection
Ammonia (mg/l as N)	Grab Sample	EPA Method #350.3	0.03 to 1400 NH3-N/L
Nitrite (mg/l as N)	Grab Sample	EPA Method #354.1	0.01 to 1.0mg NO2-N/L
Nitrate (as N)	Grab Sample	EPA Method #353.3	0.01 to 1.0mg NO3-N/L
Total Phosphorus (mg/l as P)	Grab Sample	EPA Method #365.3	0.01 to 1.2 mg P/L
Copper (mg/l)	Grab Sample	EPA Method #220.1	low detection limit is 0.1ppm
Iron (mg/l)	Grab Sample	EPA Method #236.1	low detection limit is 0.1ppm
Manganese (mg/l)	Grab Sample	EPA Method #243.1	low detection limit is 0.1ppm
Zinc (mg/l)	Grab Sample	EPA Method #289.1	low detection limit is 0.1ppm
Conductivity (mS/cm)	In situ Measurement	HydroLab H-20 probe	1 to 100 mS/cm
Dissolved Oxygen (%)	In situ Measurement	HydroLab H-20 probe	0 to 100 %
Dissolved Oxygen (mg/l)	In situ Measurement	HydroLab H-20 probe	0.2 to 18.8 mg/L
pH	In situ Measurement	HydroLab H-20 probe	0 to 14 units
Turbidity (NTU)	In situ Measurement	HydroLab H-20 probe	5 to 1000 NTU
Water Temperature (°C)	In situ Measurement	HydroLab H-20 probe	-5 to 50°C
Alkalinity (mg/l as CaCO3)	Grab Sample	EPA Method #310.1	All concentration ranges of alkalinity
Hardness (mg/l as CaCO3)	Grab Sample	EPA Method #130.2	All concentration ranges of hardness

known until many more years of research were preformed and samples were either collected from all available streams or collected using a probabilistic samplingdesign that could accurately estimate the condition of all Georgia streams, another way of gauging the method's effectiveness had to be used. Using data available from the project, I judged the effectiveness of the method by the following four criteria:

1. Were more of the primary sites sampled as candidate reference sites than were the alternate sites?
2. Was the water quality of the GIS sites unimpaired?
3. Did the GIS sites have the same or better geographical coverage, water quality, habitat, and ecological integrity (as judged using published metrics of benthic macroinvertebrates) as the BPJ sites?
4. Did the GIS sites meet the criteria for, or compare favorably with, the information published on reference sites in other states?

These four assessments would characterize the capability of the method relative to other methods.

The determination of whether the water quality of the candidate reference sites was impaired was made by comparing the water chemistry data against national standards (for those parameters where they exists), and by comparing them to published data on water quality in other streams in the region. Water chemistry data were also compared, on a sub-ecoregional basis, between the GIS sites and the BPJ sites. This same approach was also used to compare the sites by habitat assessments. The comparisons were tested for statistical

significance by calculating 95% confidence intervals for each measurement and examining them to see if they overlap (in which case they would not be significantly different) (Graybill and Iyer 1994).

To compare the ecological integrity of the GIS and BPJ sites, the benthic macroinvertebrate species data were analyzed following the method described in Rothrock et al. (1998). A Composite Normalized Metric (CNM) was calculated by dividing each separate metric score by the largest score so metric scores would vary between zero and one, and then summing all of the metric scores into a single score for comparison between sites. The reciprocal of the metrics that become smaller with increased ecological integrity was used to calculate the CNM, so a higher CNM score is indicative of higher biologic integrity. Two sets of metrics were used in this comparison as shown in table 2-9. The metric suggested by Rothrock et al. (1998) was based on a general set of metrics recommended in the EPA Rapid Bioassessment Protocol (Plafkin et al. 1989). The other set of metrics was chosen by Stribling et al. (1998) for assessing ecological integrity of non-coastal plain streams in Maryland as part of the Maryland Biological Stream Survey (MBSS).

Where measurements were equivalent to the measurements made as part of the Maryland Biological Stream Survey (see table 1-2), the measurements for both sets of sites were compared to Maryland's standards for reference sites to determine how many of each type (GIS and BPJ) would be considered reference using that set of criteria

Table 2-9. Summary of metrics used in characterizing ecological integrity from Rothrock et al. (1998) and Stribling et al. (1998).

	Metric	Ecological Relevance
Rothrock-MBSS	Taxa Richness	The richness of the community indicates biodiversity of ecosystems and is used as a quantitative measure of stream water and habitat quality. Taxa richness generally decreases as a stream ecosystem degrades.
	EPT Richness	The richness of the intolerant insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) can indicate stream condition, since they tend to become scarcer with increasing disturbance.
Rothrock et al. (1998)	Total Abundance	Total number of organisms sampled can have variable response to stream impairment, but will generally decrease as a stream ecosystem degrades.
	EPT Abundance	The number of the these generally intolerant insects can indicate stream condition, since the organisms themselves also tend to become more scarce with increasing levels of disturbance
	Percent Dominant Taxa	The proportion of the entire community composed of the most abundant taxa can be used to examine community balance. A community dominated by relatively few taxa is indicative of stress.
	Biotic Index	An index based on the tolerance of different organisms to pollution and stress. Tolerance values were based on values developed by Lenat (1993), or given in the RBP manual (Barbour et al. 1999)
	EPT : Chironomid	The ratio of EPT to Chironomids (midges). Decreasing ratios indicate stress since Chironomids tend to increase with increasing organic enrichment.
	Shredders: Total	Measure of distribution among functional feeding groups, shredders will decrease due to riparian zone impacts and can be indicators of toxins.
	Scrapers to Filterers	Shifts in functional feeding group between the scrapers who increase with increasing diatom abundance and filterers who increase with increasing filamentous algae, indicate an over abundance of certain food sources.
MBSS (Stribling et al. 1998)	Number of Ephemer-optera taxa	The richness of mayfly taxa indicates the ability of a stream to support these intolerant insects. Organic enrichment and excess fine sediment will often reduce the diversity of mayflies.
	Number of Diptera taxa	Diptera as an order are relatively diverse and Dipterans are variable in their tolerance to stress. However, a high diversity of Diptera taxa generally suggests good water and habitat quality.
	Percent Ephemer-optera	The dominance of the community by mayflies can indicate the relative success of these pollution intolerant individuals in sustaining reproduction. Stresses will reduce the abundance of mayflies relative to others
	Number of Intolerant Taxa	Intolerant taxa are the first to be eliminated by perturbations, since they are often specialists with specialized habitat or water quality requirements. Taxa with tolerance ratings from 0 to 3 were considered intolerant.
	Percent Tolerant	As perturbation increases, tolerant individuals (tolerance values 7 - 10) tend to predominate in the sample. Intolerant individuals become less abundant as stress increases, leading to more individuals in tolerant taxa.
	Percent Tanytarsini of Chironomid	The tribe Tanytarsini is a relatively intolerant group of midges. The degree to which they represent the total number of midges indicates the general sensitivity of the midge assemblage. A high percentage of Tanytarsini among the midges may indicate lower levels of anthropogenic stress.
	Percent Collectors	Abundance of detritivores typically decreases with increased disturbance. This ecological response may be a food web effect, where organic material becomes scarce or unsuitable with increased perturbation.

RESULTS.

Using the final selection method of ranking catchments based on the distributions of land use and then choosing the top five or five percent of catchments in a sub-ecoregion as possible candidate reference sites, 157 out of the 2158 possible catchments were chosen as primary possible candidates and another 157 were chosen as alternates. The land use characteristics and distribution of these sites are given in table 3-1 and figure 3-1, respectively. Of the 78 candidate reference sites selected by GIS and that were also sampled, 59 % were primary sites that were either one of the top five sites or top five percent of sites as ranked by land use. The remaining sites sampled were all in the second five or five percent. A summary of the reasons that the other primary sites were not sampled is given in table 3-2. Over half of these sites were not sampled because they appeared satisfactory, but other catchments appeared superior, they were not representative of the region, or they were dry due to the ongoing drought. Twenty-two of these primary sites were visibly impaired, with six of these impaired due to obvious recent changes in land use (mostly forest clear cuts). The sites that remained unvisited were due to a lack of time to visit and sample all sites with the field crews available. Also, the subdivision of the Blueridge Ecoregion part way through the sampling season, increased the number of sub-ecoregions to be sampled without increasing the time or number of crews available to sample.

Cheng Gu, Salini Pillai, Michele Pollock, and myself tested the water quality at each of the sites and the summary statistics of the results for all of the GIS

Table 3-1. Land use summary of candidate reference sites.

Ecoregion/ Sub-ecoregion	Primary Possible Candidate Reference Sites										Sampled Candidate Reference Sites									
			Urban		Agrarian		Barren		Forest			Urban		Agrarian		Barren		Forest		
	# sites	Mean Size (km^2)	Mean %	Range %	Mean	Range	Mean	Range	Mean	Range	# sampled	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Piedmont Ecoregion 45																				
45a	5	47	0.8	0-2	6	1-10	0.4	0-1	93	89-98	2	0.1	0-0	8	6-10	0	0-0	91	89-94
45b	20	36	0.2	0-1	4	0-14	1.6	0-4	92	80-99	4	0.3	0-1	4	1-11	1	1-1	93	86-99
45c	4	50	0.0	0-0	11	2-16	3.5	2-5	85	79-97	3	0	0-0	13	12-15	5	1-8	82	77-87
45d	5	27	0.1	0-0	3	1-5	2.3	0-6	95	92-98	4	0.1	0-0	6	1-12	3	0-6	91	85-97
45h	5	26	0.2	0-0	12	2-21	0.1	0-0	87	79-98	5	0.2	0-0	7	1-13	3	0-10	90	84-98
45	39	37	0.2	0-2	5.6	0-21	1.5	0-6	91	79-99	18	0.2	0-1	7	1-15	2	0-10	90	77-99
Southeastern Plains Ecoregion 65																				
65c	5	29	0.3	0-1	4.6	0-10	4.1	1-6	88	80-94	2	0.2	0-0	5	1-10	5	5-5	86	80-92
65e	5	36	1.5	0-3	1.7	0-6	2.8	0-4	90	86-93	5	0.9	0-2	2	0-6	4	3-5	89	86-93
65g	7	26	0.0	0-0	37	30-46	3.2	2-4	48	37-62	3	0.1	0-0	31	30-33	4	3-4	47	37-58
65h	11	26	0.5	0-2	34	7-55	5.4	2-10	42	22-63	5	1.2	0-2	31	16-51	8	5-10	46	28-63
65k	7	27	0.0	0-0	5.8	0-14	3.0	1-7	87	53-95	5	0	0-0	7	1-14	5	2-7	82	53-92
65l	21	25	0.0	0-0	28	6-45	6.5	0-15	60	45-82	4	0.0	0-0	26	11-40	10	7-15	57	48-67
65o	5	23	0.5	0-1	16	2-35	7.8	5-11	54	44-64	3	0.8	0-1	21	6-35	9	5-12	53	44-57
65	61	27	0.3	0-3	22	0-55	4.8	0-15	55	22-95	27	0.5	0-2	17	0-51	6	2-15	66	28-93
Blueridge Ecoregion 66																				
66d	5	59	0.0	0-0	0.1	0-0	0.0	0-0	100	100-100	3	0	0-0	0	0-0	0	0-0	100	100-100
66g	5	48	0.0	0-0	0.1	0-0	0.0	0-0	100	100-100	2	0	0-0	0	0-0	0	0-0	100	100-100
66j	5	31	0.1	0-0	4.1	3-6	0.2	0-0	96	93-97	2	0	0-0	4	4-4	0	0-0	96	96-96
66	15	46	0.0	0-0	1.4	0-6	0.1	0-0	99	93-100	7	0	0-0	1	0-4	0	0-0	99	96-100
Ridge & Valley And Cumberland Plateau Ecoregions 67 & 68																				
67f-i	5	48	0.4	0-1	15	6-27	1.7	0-6	83	71-91	4	0.2	0-0	13	7-18	1	0-2	86	82-91
67g	5	26	0	0-1	8.4	5-14	1.1	0-2	90	86-92	4	0.1	0-0	15	8-24	3	0-9	82	76-90
67h	5	8	0.0	0-0	1.0	0-2	0.0	0-0	99	98-100	4	0	0-0	3	1-6	4	0-14	93	80-99
68c-d	5	52	0	0-1	7.9	3-13	1.1	0-4	91	87-97	4	0.2	0-1	9	3-13	1	0-3	90	86-97
67-68 Total	20	33	0.2	0-1	8	0-27	1.0	0-6	91	71-100	16	0.1	0-1	10	1-24	2	0-14	88	76-99
Coastal Plains Ecoregion 75																				
75e	5	38	0.0	0-0	4.8	0-9	3.5	0-8	58	46-70	3	0.1	0-0	5	2-6	8	8-8	52	48-54
75f	7	32	0.2	0-1	1.2	0-4	3.5	2-7	68	62-73	2	0.5	0-1	3	3-3	4	3-5	70	67-73
75h	5	31	0.0	0-0	16	1-40	9.5	5-17	69	40-90	4	0.1	0-1	25	4-40	7	5-11	60	40-83
75j	5	38	0.1	0-0	0.8	0-3	1.1	0-3	52	0-70	1	0	0	1	1	10	10	55	55
75	22	27	0.1	0-1	5.3	0-40	4.3	0-17	62	0-90	10	0.2	0-1	12	1-40	7	3-11	59	40-83
GA	157	34	0.2	0-3	8.2	0-55	2.2	0-17	90	0-100	78	0.3	0-2	11	0-51	4.1	0-15	78	28-100

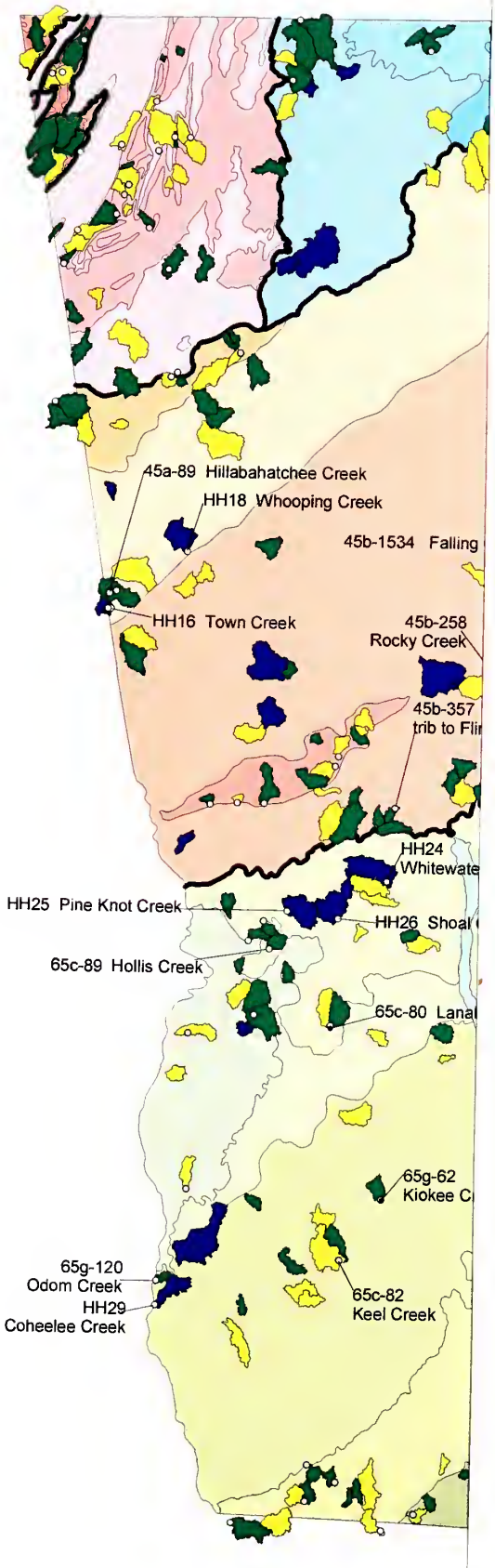

45a-89 Hillabahatchee Creek
HH18 Whooping Creek
45b-1534 Falling
HH16 Town Creek
45b-258
Rocky Creek
45b-357
HH24
HH25 Pine Knot Creek
HH26 Shoal
65c-89 Hollis Creek
65c-80 Lanal
65g-62
65g-120
Odom Creek
HH29
Coheelee Creek
65c-82
Keel Creek

Figure 3-1. Possible candidate reference sites and candidate sites sampled. Sites that are referred to in the text have name and site number annotated.

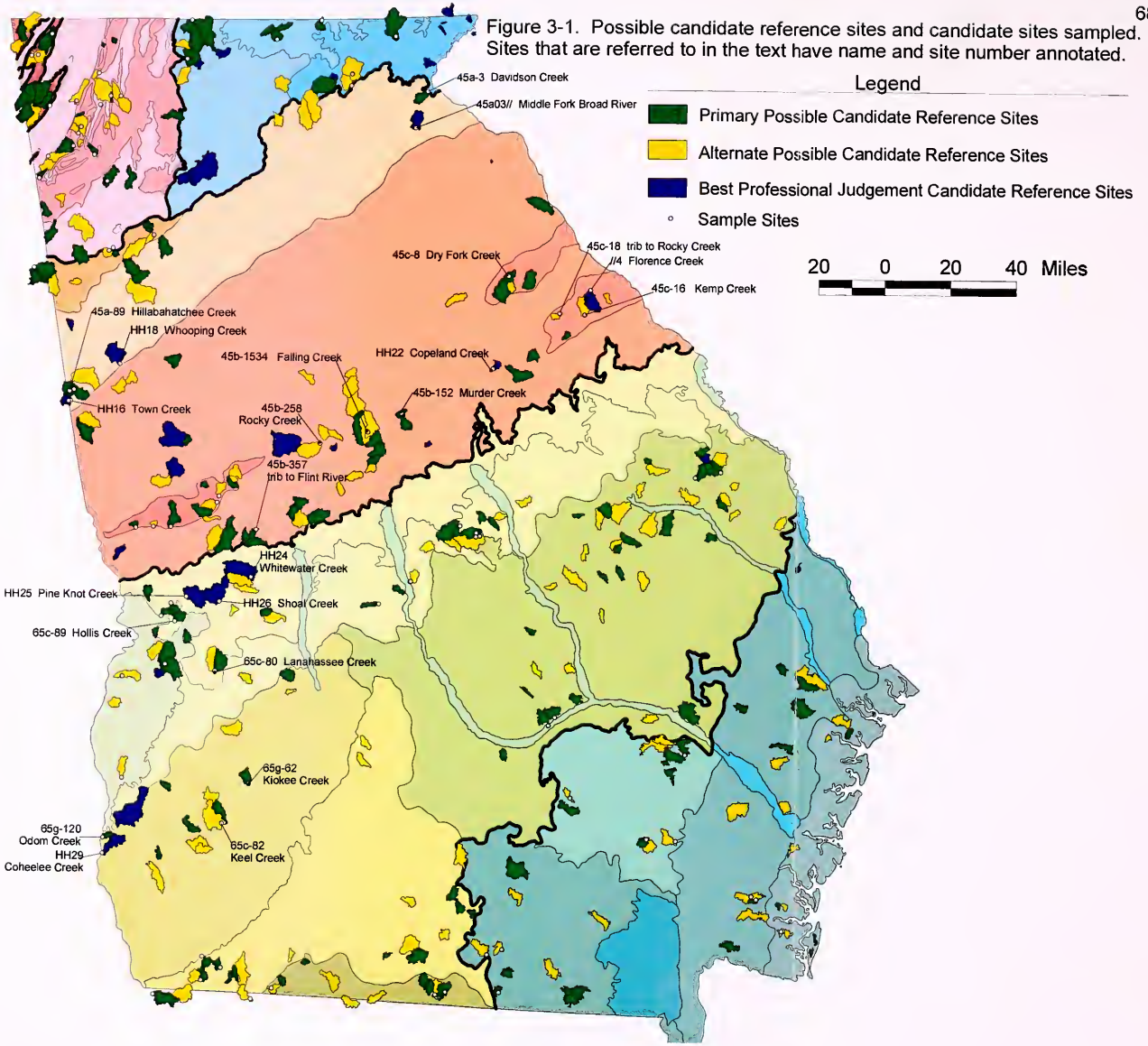


Table 3-2. Reasons possible candidate sites were not sampled.

Reasons Not Sampled	Number of Sites
Dry	25
OK, but Not Selected as Candidate	24
Unrepresentive of Region	5
Impaired	22
Access Problems	19
Not visited	16
total	111

candidate reference sites are given in table 3-3. All of the sites sampled met the EPA's National Primary and Secondary Drinking Water Regulations (USEPA 1999; National primary drinking water regulations 2001) for those chemical parameters that we measured with only three exceptions. The standards that were exceeded are the 0.3 mg/L standard for iron, which was exceeded in 12 instances, the 5 NTU standard for turbidity which was exceeded in 39 instances,

Table 3-3. Summary statistics of water chemistry data from candidate reference sites.

	Median	90%	Maximum
pH	6.760	7.350	8.100
Conductivity	0.061	0.334	1.206
Dissolved Oxygen	9.590	5.600	2.310
Turbidity	4.700	16.300	39.600
Ammonia	0.037	0.070	0.092
Nitrate (as N)	0.064	0.370	1.006
Nitrite	<LOD	<LOD	0.015
Total Phosphorus	0.029	0.115	1.138
Copper	<LOD	<LOD	<LOD
Iron	<LOD	0.863	12.989
Manganese	<LOD	<LOD	0.772
Zinc	<LOD	<LOD	<LOD

and the 0.05 mg/L standard for manganese which was exceeded in only one instance (see figures 3-2 through 3-6).

The results of the analysis of the possible candidate reference sites chosen by best professional judgment (BPJ) is given in table 3-4. These sites only covered 15 of the 23 different sub-ecoregions that I analyzed across the state.

Table 3-4. Results of analysis of best professional judgment sites.

Source	# of Sites	# of Sub-ecoregions	# also chosen by GIS	rejected for land use	rejected for size	rejected for sub-ecoregion overlap	# visited	# sampled	# impacted
Hoke Howard	35	11	8	1	4	3	15	7	8
Becky	8	5	3	0	0	0	2	1	1
Original List	35	5	12	11	1	0	9	1	8
Total	78	15	23	12	5	3	26	9	17

The regions not covered by BPJ sites included 45d, 45h, 66j, 67f&l, 67g, 75e, 75h, and 75j. The mountainous areas of the state were the best represented, with 19% of these sites in two sub-ecoregions of the Blueridge Mountains, 66d & 66g. Thirty percent of the BPJ sites had also been chosen by GIS, but another 26% had been rejected by GIS analysis because they were either too big, were not at least 80% in a single sub-ecoregion, or had land use impacts that were worse than the mean of all catchments in that sub-ecoregion. Twenty-six of the remaining 35 BPJ sites were assessed on the ground, and nine of these were sampled as candidate reference sites. Many of the 17 sites that were assessed, but rejected as impaired by field crews were impacted by sediment and had

Figure 3-2. Frequency and cumulative percentage of turbidities of water at GIS selected reference sites.

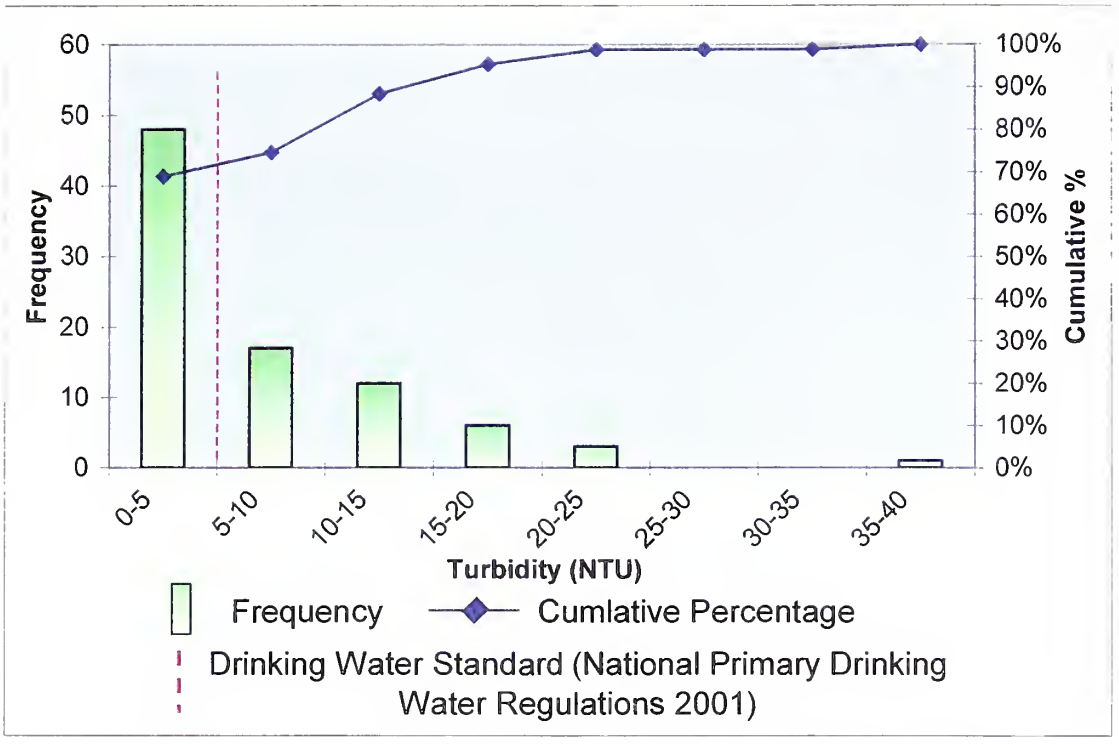


Figure 3-3. Frequency of metal concentrations in water samples from GIS selected reference sites.

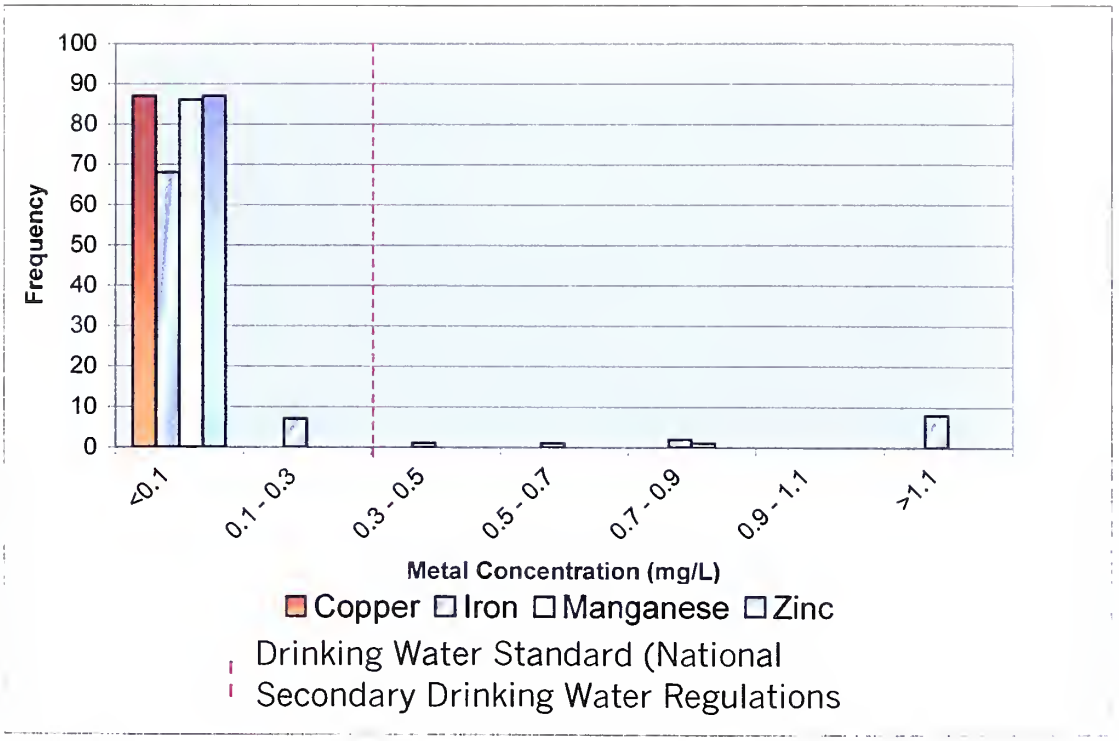


Figure 3-4. Frequency and cumulative percentage of nutrient concentrations in water samples from GIS selected reference sites.

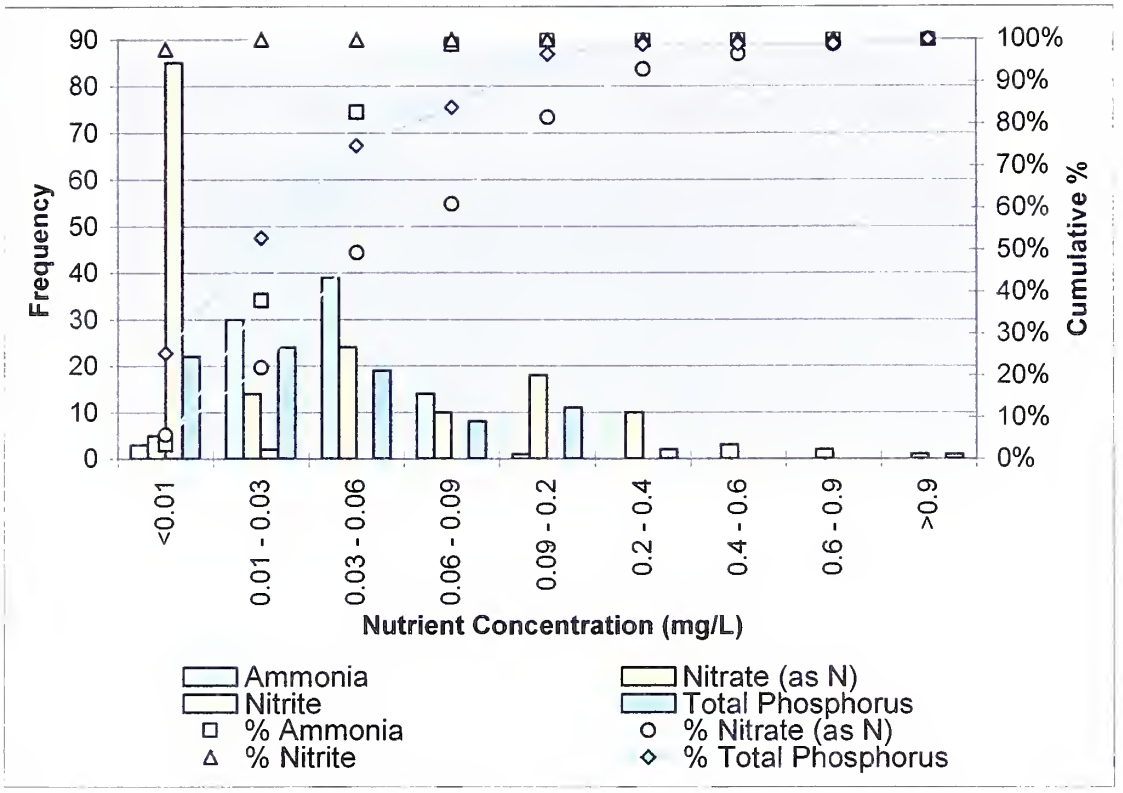


Figure 3-5. Frequency and cumulative percentage of conductivities of water at GIS selected reference sites.

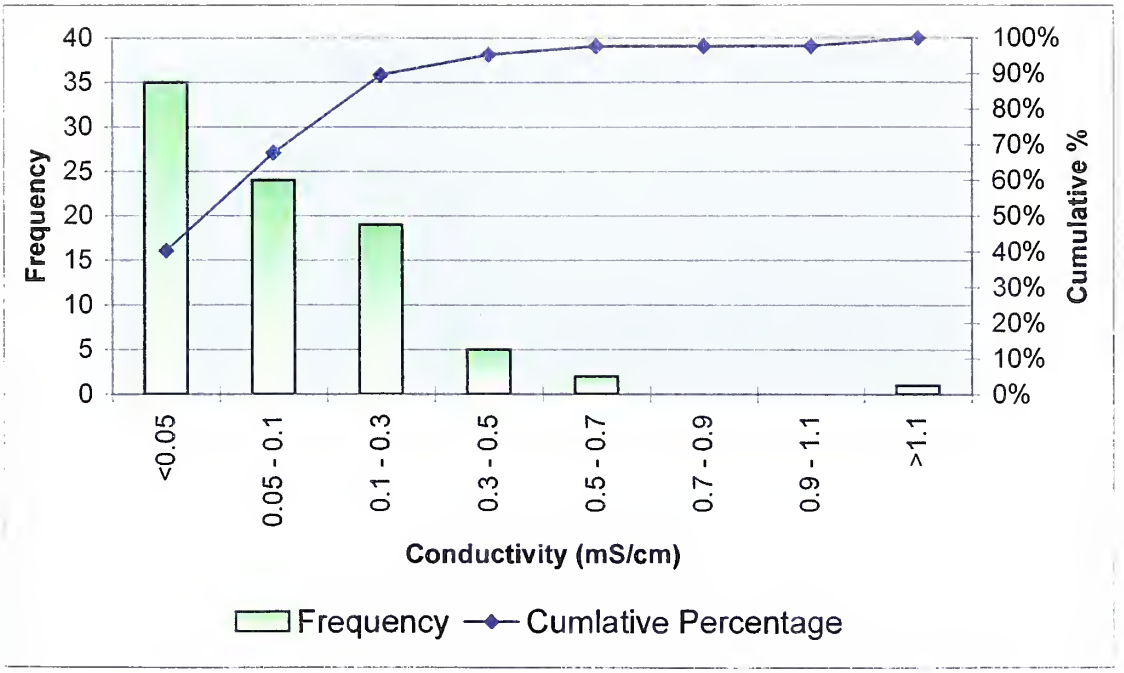
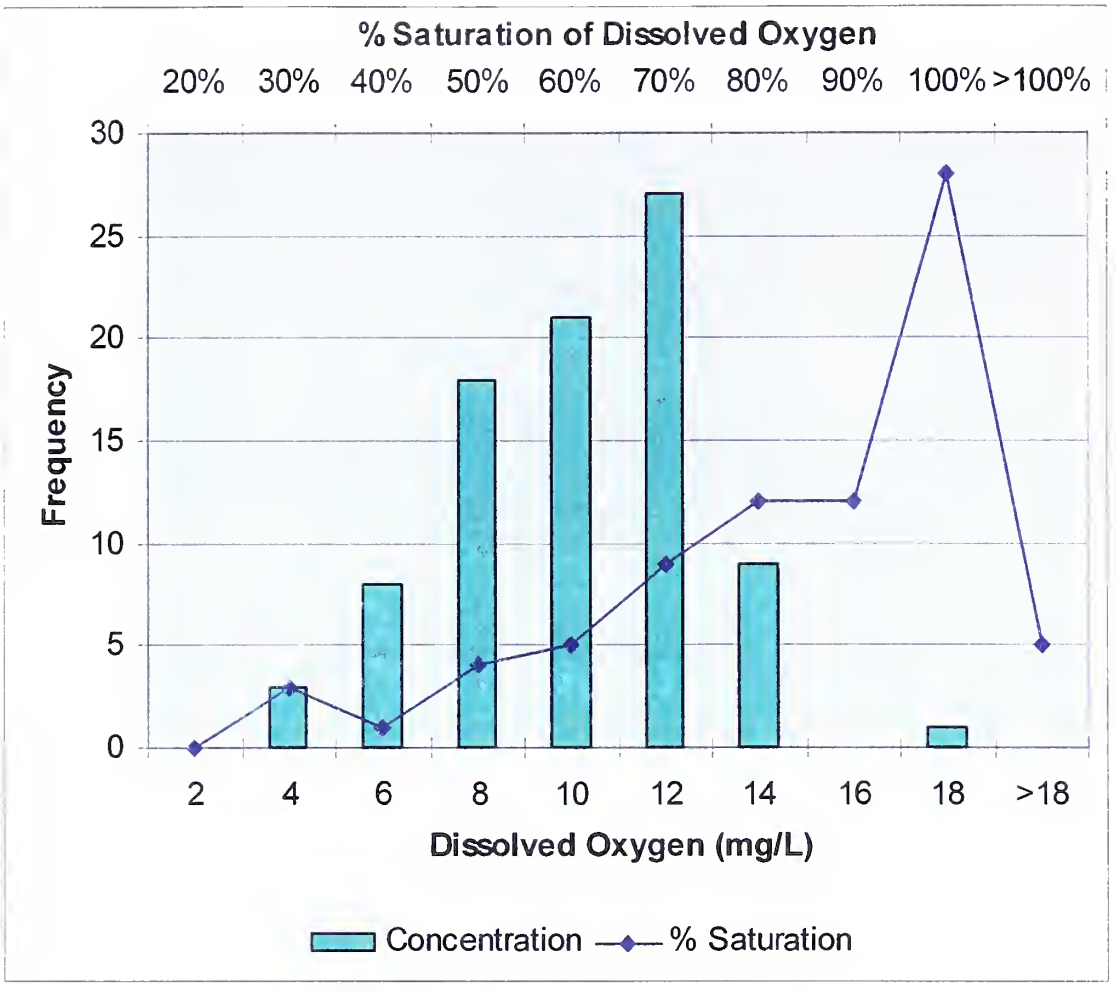


Figure 3-6. Frequency of dissolved oxygen concentrations and percent saturation of water at GIS selected reference sites.



evidence of construction in the catchment. HH23, Swan Creek, had been visited during July 2000 as part of the effort made to ground truth streams prior to sampling and had been chosen as a candidate site. However, when a sampling crew returned during December 2000, construction upstream had already impacted the site.

The GIS selected candidate reference sites were also compared to those chosen by best professional judgment, in terms of their water quality, habitat and

biology. Five sub-ecoregions that had both GIS and BPJ sites and that were sampled were used for this comparison, 45a, 45b, 45c, 65c, and 65g (see figure 3-1). Both nutrient and metal concentrations in these five sub-ecoregions were very low, with all of the measurements except one below 1 mg/L. As figures 3-7 through 3-11 demonstrate, nutrient concentrations for GIS sites were equal to or less than the BPJ sites in all but five cases. All sites, both GIS and BPJ, met the two standards set by the EPA for the nutrients nitrate and nitrite. In sub-ecoregion 45b, two of the four GIS sites were significantly greater than the one BPJ site in the concentration of ammonia and nitrate (see figure 3-7). However, two other sites were statistically the same in these same cases. Two GIS sites in sub-ecoregion 65g were also significantly greater in total phosphorus than the single BPJ site, but again one of the GIS sites was equal to the BPJ site (see figure 3-11). In sub-ecoregion 45c, all three of the GIS sites had significantly greater amounts of both nitrate and total phosphorus than the one BPJ site sampled (see figure 3-9). This case was confused however by the fact that this one BPJ site, //4 (Florence Creek), was impoverished in invertebrate fauna. The lack of invertebrates was thought to be because of the current drought, with the water that was present being relatively new water that had not yet been recolonized. If this water was mostly due to an increase in base flow as opposed to run off, the low amounts of nutrients in it were to be expected.

For these same five sub-ecoregions, all of the metal concentrations were below the limit of detection of our methods, except two sites in 65c. Figure 3-12 shows that the BPJ site (HH24, Whitewater Creek) had a much higher iron

Figure 3-7. Comparison of nutrient concentrations among sub-ecoregion 45a BPJ and GIS candidate reference sites.

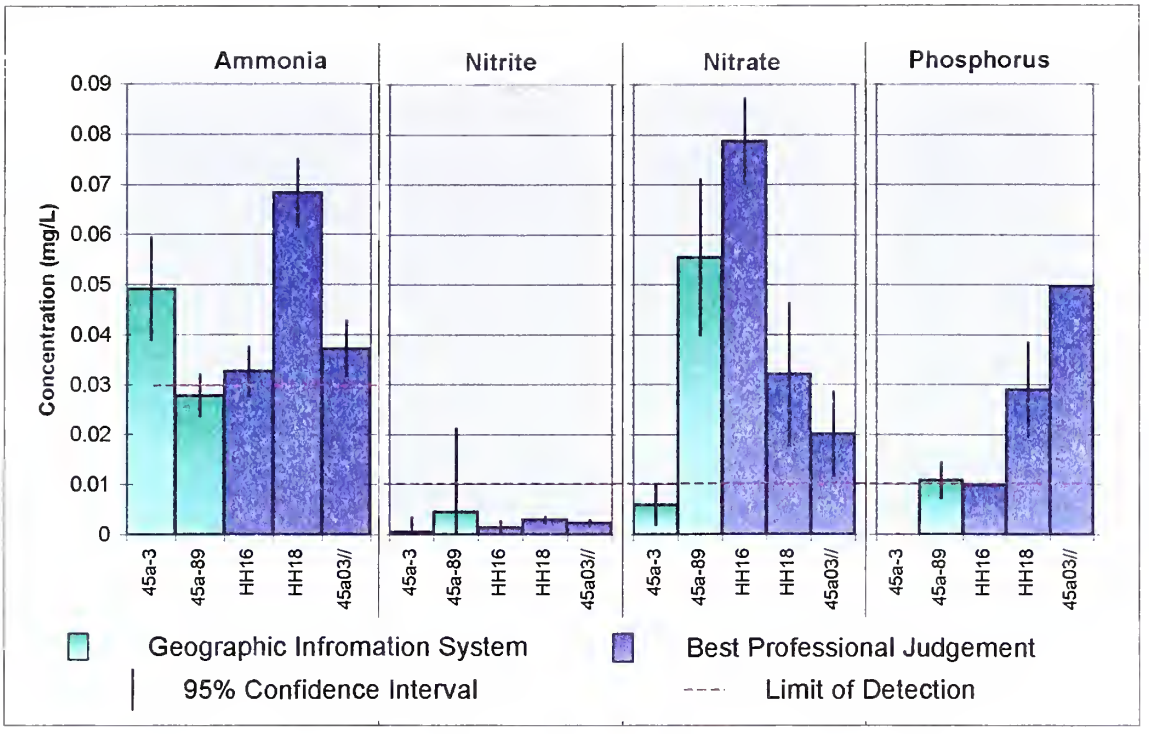


Figure 3-8. Comparison of nutrient concentrations among sub-ecoregion 45b BPJ and GIS candidate reference sites.

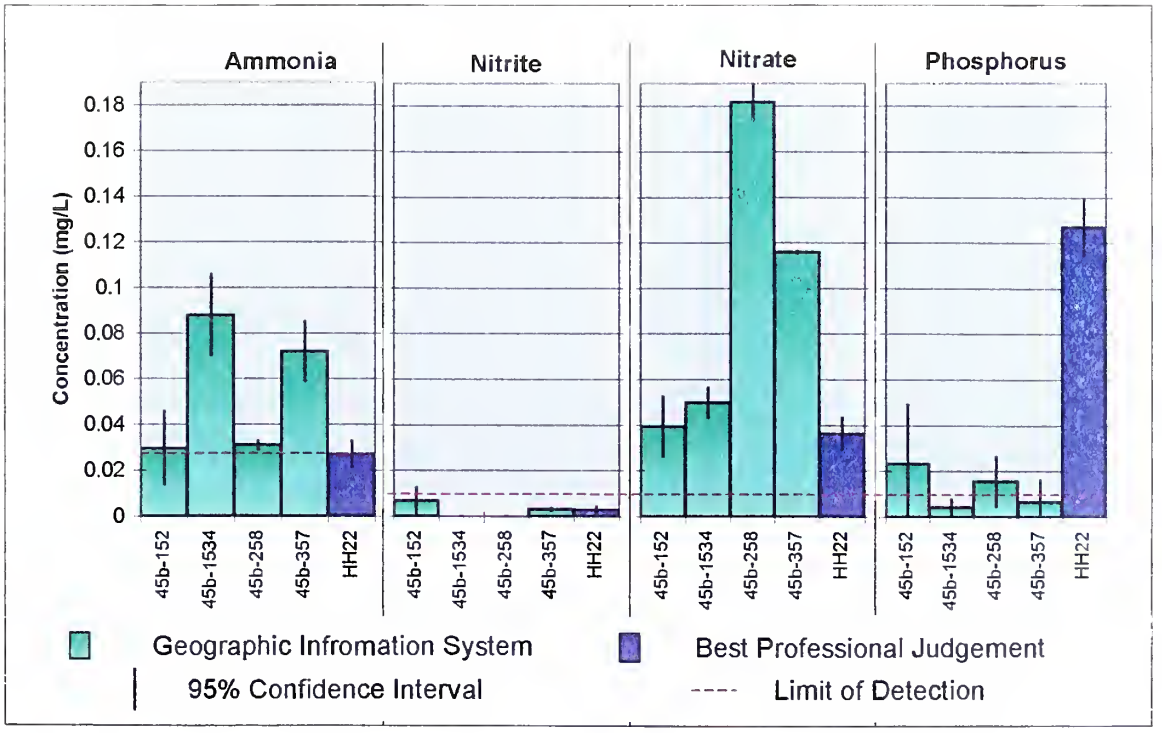


Figure 3-9. Comparison of nutrient concentrations among sub-ecoregion 45c BPJ and GIS candidate reference sites.

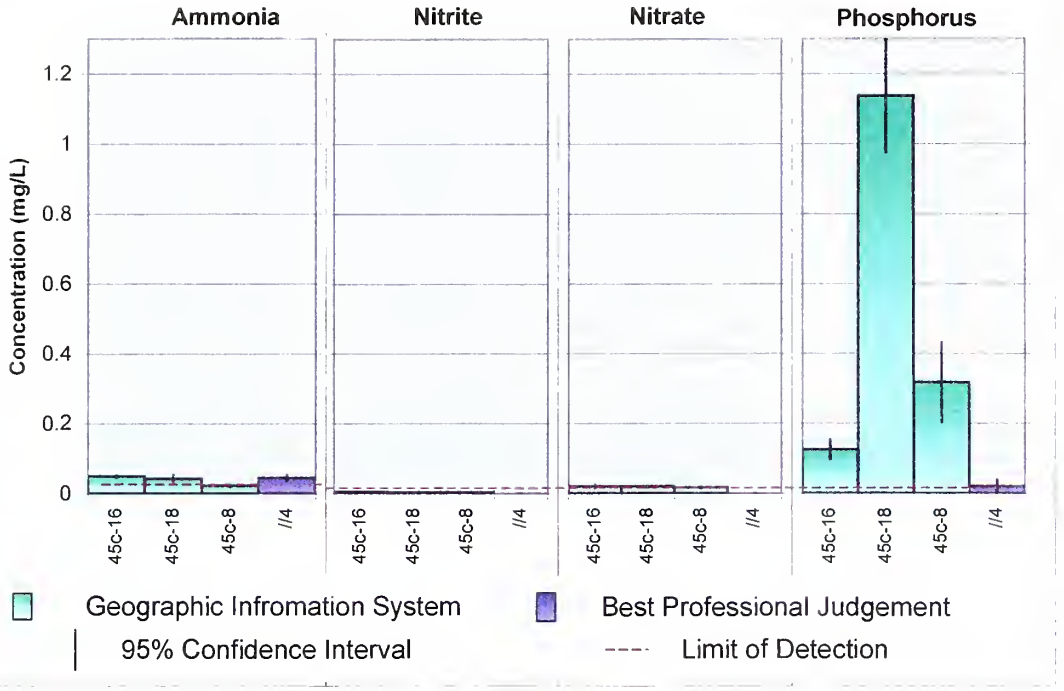


Figure 3-10. Comparison of nutrient concentrations among sub-ecoregion 65c BPJ and GIS candidate reference sites.

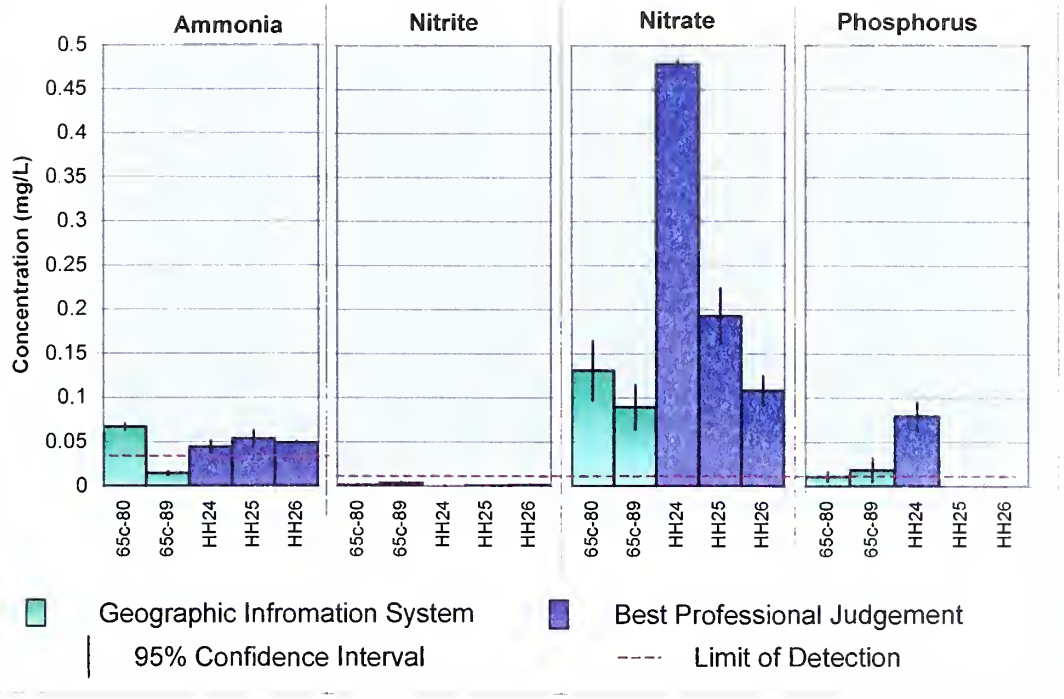
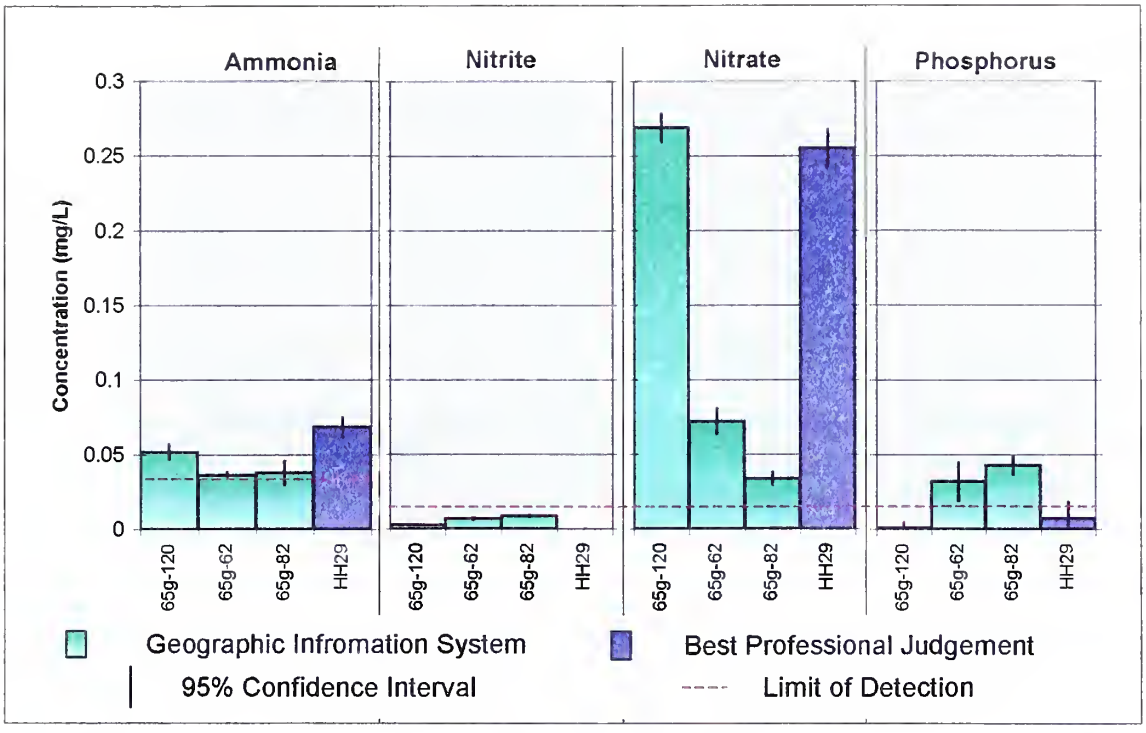


Figure 3-11. Comparison of nutrient concentrations among sub-ecoregion 65g BPJ and GIS candidate reference sites.



concentration (twice the national secondary standard) than the GIS site (65c-89, Hollis Creek).

While all of the GIS sites received sub-optimal scores (113 – 165) for the visual habitat assessment, four of the nine BPJ sites received optimal scores (166 – 200). Figure 3-13 shows that BPJ sites were generally given higher scores than GIS sites, with means of 165 and 150 respectively. However, when viewed one sub-ecoregion at a time, the GIS sites were not very different from the BJP sites, with the means being within ten points of each other in three of the five cases.

The comparison of benthic macroinvertebrate communities using the general set of metrics used by Rothrock et al. (1998) is shown in figure 3-14. Using this set of metrics, the GIS sites were either approximately equal to, or better than the BPJ sites. However, the results are quite different using the specific set of metrics selected to be used as part of the Maryland Biological Stream Survey (MBSS) shown in figure 3-15. While three of the sites do not change significantly between the two metric sets (45a-3, HH16 and HH18), 45a-89 and 45a03// are dramatically effected. One of the causes of this change is the different ways of accounting for the presence/absence of tolerant organisms. While the inverse of the tolerance value used by Rothrock et al. (1998) accounts for every organism in the sub-sample, the MBSS looked at only the most tolerant and intolerant organisms. The MBSS also did not use organism abundance as a measure.

The comparison of the candidate sites sampled in this study to the standards

Figure 3-12. Comparison of iron concentrations between sub-ecoregion 65c BPJ and GIS candidate reference sites.

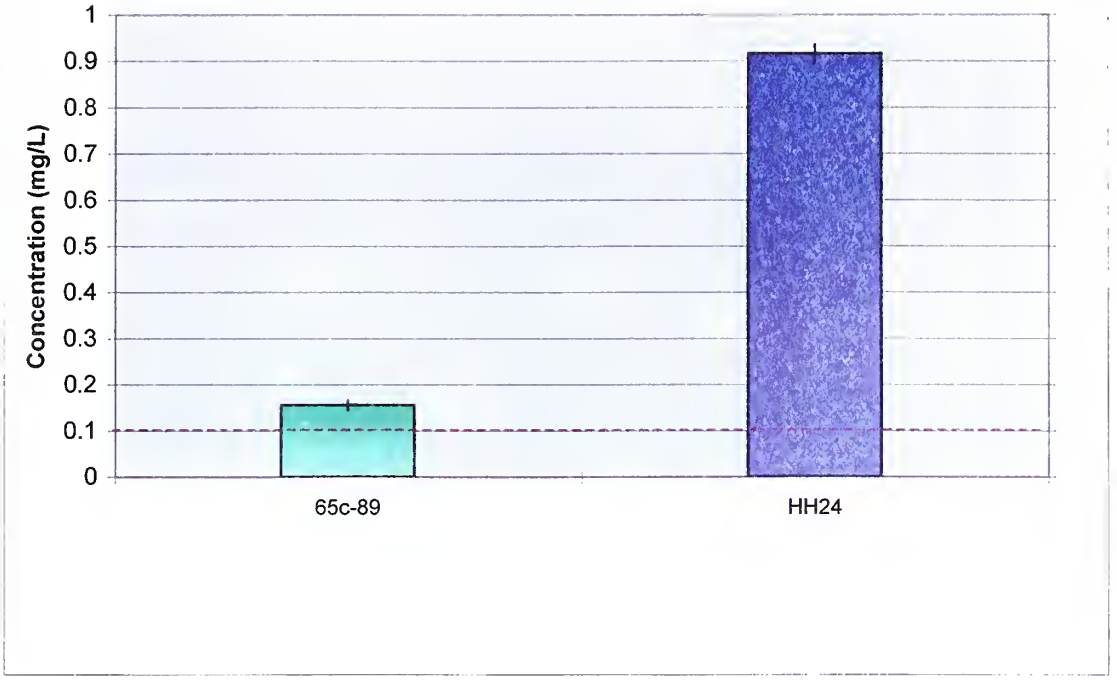


Figure 3-13. Comparison of habitat assessments among GIS and BPJ candidate reference sites by sub-ecoregion.

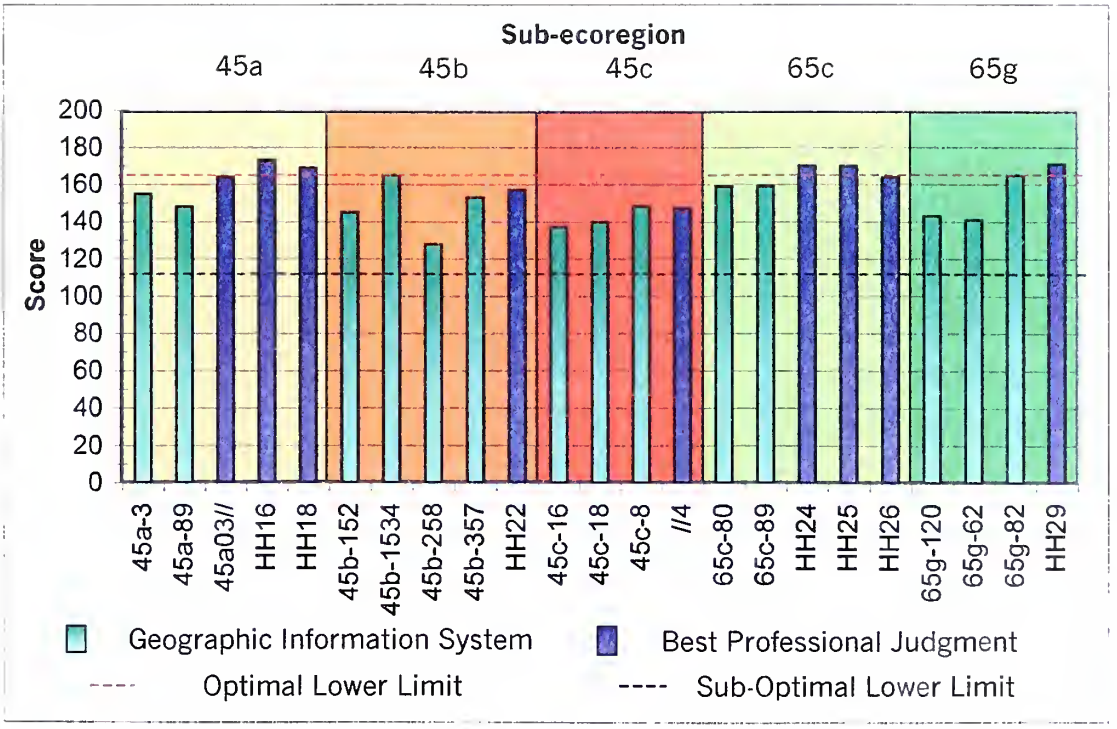


Figure 3-14. Comparison of composite normalized metrics among sub-ecoregion 45a GIS and BPJ sites using Blackfoot River study metrics.

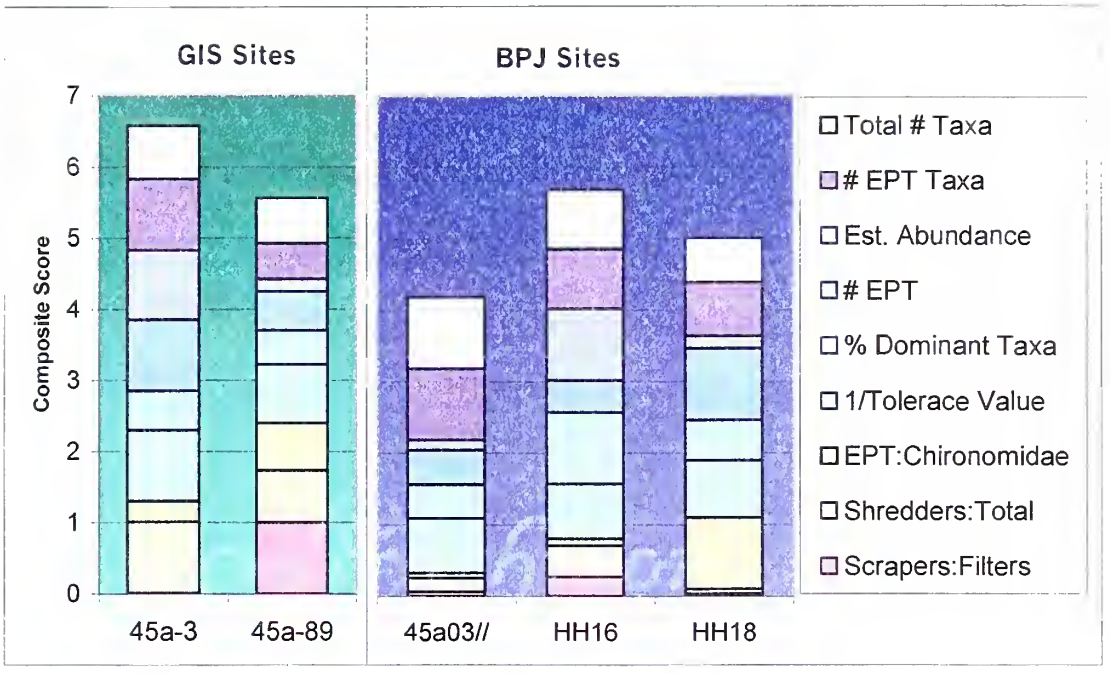
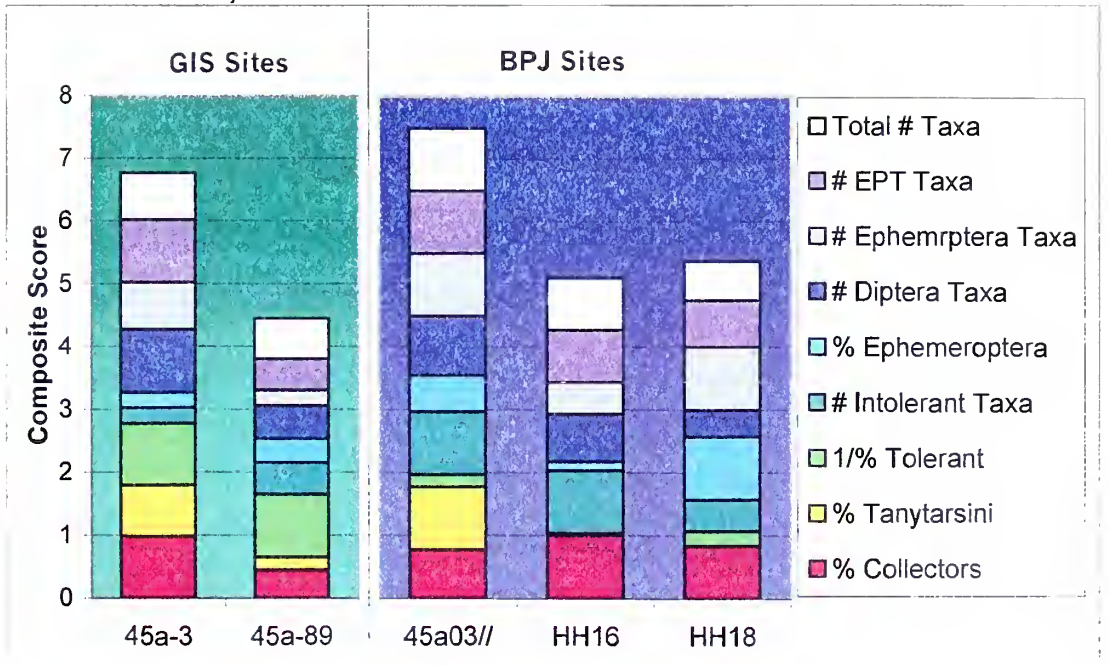


Figure 3-15. Comparison of composite normalized metrics among sub-ecoregion 45a GIS and BPJ sites using Maryland Biological Stream Survey Metrics.



developed for reference sites as part of the MBSS is shown in table 3-5. Sixty-five percent of the sites identified by GIS met all of Maryland's criteria for being a reference site. Since Acid Neutralization Capability (ANC) can be a function of geology as much as a function of anthropogenic impact (Allen 1997), this criterion might not be applicable to Georgia. Looking at all criteria except ANC, approximately three quarters both the GIS and the BPJ sites met the remaining criteria.

Table 3-5. Comparison of candidate sites against Maryland reference site criteria from Stribling et al. (1998).

Criteria	# of sites not meeting criteria		
	all sites	GIS	BPJ
pH ≥6 (if blackwater stream, ph<6 and DOC ≥8 mg/l)	5	5	0
Acid Neutralization Capability (ANC) ≥50 meq/l	13	10	3
Dissolved $O_2 \geq 4$ ppm	4	3	1
Nitrate-N ≤4.2 mg/l	0	0	0
Urban Land use ≤20% of catchment area	0	0	0
Forested land use ≥25% of catchment area	0	0	0
Instream habitat optimal or sub-optimal	0	0	0
Riparian buffer width ≥15m	14	13	1
No channelization	2	2	0
No point source discharges	0	0	0
All criteria	**32**	**27**	**5**
All criteria, except ANC	22	20	2
% success, all criteria	**63**	**65**	**44**
% success, all except ANC	75	74	78

DISSCUSSION AND CONCLUSIONS.

If land use patterns analyzed by a GIS are to be considered effective at identifying reference sites it must be able to identify enough of the least impacted sites available to be statistically significant and cover the range of natural conditions of an area in a cost-effective manner. GIS should also perform as well as, or better than, current methods of identifying reference sites based on local knowledge of experts. Judgment of the validity of the least impacted sites requires either data on all possible streams or a probabilistic sampling design to ascertain the current range of stream conditions available. While a final judgment on the method's ability to identify reference sites will have to await future studies of this type, currently available data indicate that the majority of streams identified were not impaired.

Since 20% of the sites with the lowest anthropogenic land use (the primary possible candidate reference sites) were obviously impaired, this method still requires that a subjective assessment of the stream be made before it is sampled. The misidentification of sites probably stems from several sources. The fact that land use is constantly changing is one of the primary causes of misidentification. Twenty-one percent of the BPJ sites were rejected as impacted even though at one time they were judged to be reference quality. Six of the 22 possible candidate GIS sites, now impacted, were affected by obvious recent changes in land-use, including the rapid urbanization around Atlanta, the clear cutting of forests, and, in one case, the impoundment of the stream to make a reservoir. Another cause of misidentification might be that moderate agricultural

land use does not predict stream impairment in catchments with less than 50% agricultural land-use. This is supported by the fact that half of the alternate sites that were sampled as candidates instead of the primary sites had agricultural land use between 10 and 50 percent. This low correlation of stream condition and agricultural land use is probably due to differences in land use that are below the resolution of the data available. This would include differences in agricultural practices such as fencing pastures from streams, contour plowing, and fallowing fields. A third reason could be the artificiality of using four "bins" to score land use in terms of distribution. This four score system will lack sensitivity to small changes in land use between catchments.

Water quality criteria for streams are generally based on data from reference sites (USEPA 2000), so judging whether the sites I selected using GIS are "reference sites" using these criteria is a bit backwards. However, EPA guidance does suggest using published threshold values for nutrient loading if no other resources exist. It does add however, that most of these values are based on cobble bottom streams in northern temperate climates and these values should be used with caution in sandy bottomed or Southeastern streams. As shown in table 4-1, published values also cover a wide range of thresholds for nutrient impairment. Using even the most restrictive standard for total phosphorus (less than 0.02 mg/L), 43% of the GIS sites would be considered unimpaired. Eighty-five percent meet the more generous standard of less than 0.09 mg/L and all but two sites (45c-8 and 18) were below the maximum value of the reference sites for Tennessee (USEPA 2000) and the mean value of agricultural streams in

Table 4-1. Published literature threshold values for nutrient impairment.

Source	Nitrogen (mg/L)	Type of measurement	Phosphorus (mg/L)	Type of measurement
Dodds et al. 1998, cited in USEPA 2000	1.500	Total N	0.075	Total P
Dodds et al. 1997, cited in USEPA 2000	.27 - .65	Total N	0.038-0.090	Total P
Tennessee Reference Site Maximum Values, USEPA 2000	2	NO_{2+3}	0.26	Total P
Van Nieuwenhuyse and Jones 1996, cited in USEPA 2000	0.3	Total N	0.042	Total P
Lenat and Crawford 1994, mean values for forested Piedmont streams in NC	0.08	NO_{2+3}	0.09	Total P
Lenat and Crawford 1994, mean values for Agricultural Piedmont streams in NC	0.59	NO_{2+3}	0.27	Total P
Chetelat et al. 1999, cited in USEPA 2000			0.02	Total P
Dodds and Welch, 2000	0.47	Total N	0.06	Total P

North Carolina (Lenat and Crawford 1994). The thresholds for total nitrogen are not useful, since we only measured nitrite, nitrate, and ammonia. However, 49% of the GIS sites had nitrate plus nitrite values less than mean measured for forested Piedmont streams in North Carolina and 84% had values less than the mean for North Carolina agricultural streams (Lenat and Crawford 1994). All of the candidate reference sites selected by GIS had nitrate plus nitrite values less than the maximum values for Tennessee reference sites. These comparisons indicate that all but two of the GIS candidate reference sites were not impaired by nutrient pollution.

Eight of the GIS sites did not meet the EPA's Criterion Continuous Concentration standard for iron of 1 mg/L established in the National Recommended Water Quality Criteria (USEPA 1999). However, all but two sites (65k-56 and 65o-12) had iron concentrations below the mean iron concentration for North Carolina forested streams (Lenat and Crawford 1994). Site 45c-8, in addition to having high phosphorus concentrations, also had the only significant concentration of manganese in excess of the National Recommended Water Quality Criteria (USEPA 1999). Therefore, only three of the 78 candidate sites selected by GIS appear to have had metal concentrations that might be indicative of impairment.

With 47% of the streams meeting national primary and secondary drinking water standards, and only four sites showing concentrations of either nutrients or metals that indicate possible impairment, the sites selected by GIS as candidate reference sites had relatively unimpaired water quality when compared to published standards. However, these results should be treated as only indicative, not authoritative, since these water quality standards may lack applicability to Georgia, and there is still some debate about what constitutes a threshold for judging stream impairment based on water quality data (Dodds and Welch 2000; USEPA 2000).

It is also useful to compare the streams selected by GIS as candidates against those chosen by best professional judgment (BPJ) to determine if the GIS method is selecting sites as well as this current method. The GIS method has an immediate advantage over the BPJ method in its ability to evenly cover all

portions of the state, while the BPJ method failed to recommend any sites in eight sub-ecoregions. The fact that 33% of the sites chosen by best professional judgment (after screening out those that did not meet the requirements for size and being at least 80% within a single sub-ecoregion) were also chosen by GIS shows that both methods will select the relatively unimpaired streams, if they are available. The water chemistry data from those sub-ecoregions with sites selected by both methods supports this conclusion, with all the measurements of potential nutrient contaminants being low. While, in some instances, the GIS sites had lower concentrations, and in other cases, the BPJ sites had lower concentrations, the number of these cases was approximately equal.

The BPJ sites did have better visual habitat assessment scores when compared to the GIS sites. However, the difference between the average GIS score and the average BPJ score when compared within a single sub-ecoregion ranged from 5 to 21 points. While there was not a measurement of error associated with these measurements, the mean standard deviation based on two teams assessing a random selection of eight of the same sites from across the state was 10.8, with a range of 1 to 25. This gives a 95% confidence interval of ±15 points. This means that the difference in habitat values between the GIS and the BPJ sites are not significant in three of the five sub-ecoregions. Since the BPJ sites were chosen based upon their subjective local habitat evaluation, it is hardly surprising that some of these sites have significantly better local habitat than the GIS sites. The better local habitat will improve the ecological integrity at

that site, but the habitat difference at the site scale may not be enough to compensate for land use differences at the catchment scale.

The conclusion that the GIS sites are less or equally impacted as the BPJ sites is also supported by the biological data. GIS site 45a-3 had higher metric scores than two of the three BPJ sites using both sets of metrics. Whether the other GIS site, 45a-89, is better than the BPJ sites depends on which set of metrics are used. While the MBSS metrics are geographically closer, because they were specifically chosen to assess streams in Maryland, this set may actually be less applicable than a set of generic metrics used in Montana.

The number and diversity of Ephemeroptera is much more heavily represented in the MBSS metrics, which may make them less applicable in the Ephemeropteran poor Southeast. The use of number of intolerant taxa when using the normalized scores is also somewhat deceiving. Since the numbers of intolerant taxa only varied between two and four, the difference of two taxa would change the CNM score by 0.75, a significant change since the scores only ranged from 4.5 to 7.5. The Blackfoot River metrics used the more traditional method of summarizing the tolerance value of all organisms, such as is done in the Hilsenhoff Biotic Index (Hilsenhoff 1987) or the North Carolina Biotic Index (Lenat 1993), which is much less affected by addition of a single taxon.

The choice of collectors as a measure of functional feeding group composition is also somewhat problematic. Stribling et al. (1998) noted that while the percentage of collectors did work well for identifying stress in non-coastal plain sites in Maryland, the coastal plain sites had a reciprocal relationship, with the

percentage of collectors increasing with stress. Since the metrics used in assessing sites in the Blackfoot River drainage were not chosen specifically for that area, but instead were a sampling of some of the most often used metrics, they may be more applicable to Georgia Piedmont streams. This would also support the conclusion that the GIS selected sites were as unimpaired, biologically, as the BPJ sites.

A comparison of the land use of the GIS candidate reference sites relative to the land use of reference sites for the coastal plain in other states along the eastern US is shown in table 4-2. In terms of land use, the Georgia reference sites are among the least impacted in this group. This method also identified more than three times as many sites in the coastal plain than any other state in this group. When the candidate reference sites are compared to the criteria for reference sites in Maryland, a higher proportion of GIS selected sites met all of the criteria than did the BPJ sites (65% vs. 44% respectively). However, if acid neutralization capability (ANC) is ignored because of the changes in water

Table 4-2. Comparison of the land use of reference sites (other state data is for coastal plain streams only from Maxted et al., 2000).

		Urban		Agriculture		Forest	
State	n	mean	range	mean	range	mean	range
New Jersey	6	27	14-46	18	4-50	54	36-78
Delaware	10	6	1-13	46	29-71	47	19-65
Maryland	7	3	1-9	60	25-76	36	22-73
Virginia	8	1	0-3	32	17-62	64	30-79
N. Carolina	10	1	0-5	17	0-60	82	40-99
S. Carolina	10	2	0-8	35	17-60	63	37-80
Georgia Coastal Plain GIS	37	0.4	0-2	16	0-51	64	28-93
Georgia GIS	78	0.3	0-2	11	0-51	78	28-100
Georgia BPJ	9	0.4	0-0.8	16	3-44	74	42-93

chemistry associated with the different geology in Georgia, then approximately 75% of both GIS and BPJ sites met the remaining criteria. Five of the sites that did not meet the criteria for pH may be anomalies. Two of these streams in sub-ecoregion 65e (Southeastern Plains and Hills) may have had tannic acid loading similar to blackwater streams, but not have been classified as blackwater due to their dark clay bottoms (as opposed to the white sand bottoms of most classic blackwater streams). The other three were all classified as blackwater, but had pH values between 6 and 7. These elevated pH values could have been due to elevated runoff during the winter rainy season. The proportion of GIS sites meeting all criteria except ANC and pH is 81%. The majority of the remaining sites not meeting the Maryland criteria did not have riparian buffers greater than 15 m. This is again due to the difference in choosing reference sites based mostly on local site characteristics versus choosing reference sites based mostly on catchment wide characteristics. The GIS method still managed to perform fairly well, even when compared to all of the Maryland criteria, identifying 51 reference sites compared to the 37 identified in Maryland that met all criteria.

In addition to the ability to identify the least impacted streams available, the method should also minimize time and cost. This analysis required a single desktop computer, a single GIS analyst and approximately three months of CPU and man time, including the time for method development. While this method requires a greater amount of effort and expertise, it does deliver a product of predictable quality, unlike relying upon local expertise which may vary greatly from place to place.

In the future, this method may become even more reliable. I would recommend the following changes/additions to the method that I used:

1. Analysis should be done at multiple scales. Even more of the BPJ sites would have been chosen by GIS except their catchments were at either smaller or larger scales than what I chose to analyze. I would recommend a two or three category approach, analyzing streams in the 5 to 50 km^2 and the 50 to 500 km^2 ranges. This would both increase the number of sites located and increase the amount of natural variation covered by the sites to include differences in size.

2. Additional data should be used if available. Since GIS data sets are continuously evolving and being improved, more detailed road data (to include type of road surface) might be available. The follow-on project to the development of NLCD92 by the MRLC is already underway. A new national land use data set based on year 2000 Landsat 7 imagery is scheduled for release in 2004. For rapidly changing landscapes, up to date land use data will improve the proportion of sites identified as candidates ultimately being true reference sites.

3. A better way of estimating which land is in active silvicultural use should be developed and used for areas like Georgia that have significant portions of land in silviculture. Ideally, a data set describing silvicultural land use at a relatively high resolution may someday be available (currently data on silviculture are only available for county size units and larger). If not, a better estimate of how much land is in silviculture in the southeast may be made by

combining barren and land that is exclusively evergreen forest, since both of these land types are predominate in silvicultural areas and relatively rare in natural areas. This could be done by simply adding the percentage of a catchment that is categorized as evergreen forest as another land use measure, or by looking at the patch size of areas of evergreen forest.

4. Replace the method of scoring sites based on their distributions with a z score, based on a recommendation by T.V. Beaty of the SC Department of Health an Environmental Control (personal communication, 2000). The z score is calculated by normalizing all data to the mean, so scores below the mean are negative, while those above the mean are positive. These scores can then be summed and weighted as appropriate, and used to rank sites. This approach was actually used to reassess the three new sub-ecoregions in the Blueridge. This resulted in 74% of primary sites being chosen as candidate reference sites. Of the four primary sites that were not chosen for sampling, three were not sampled due to access problems and only one was impaired.

While additional validation is still needed, the data presented here support the conclusion that candidate reference sites can be identified by analyzing land use data using GIS. Because stream condition is not always a linear function of land use, land use data are always a little out of date, and to find the best local habitat available, sites selected by GIS still need to be evaluated on site.

The method has several advantages over identifying sites using best professional judgment. This is an objective method of identifying potential

reference sites instead of relying on the subjective judgment of experts or by trying to extrapolate from limited data. The ability to rank all streams in a sub-ecoregion provides a greater number of potential reference sites that are more geographically distributed. This allows more sites to be sampled over a greater range of conditions to better define the reference condition. This method also assesses all streams, not just those that have relatively easy access as is done with sites selected using best professional judgment. Access is gained to sites that are assessed by professionals usually by public road. However, the presence of public roads in the catchment is also a form of disturbance, so the least disturbed sites, those with the most difficult access, are not generally assessed by the professionals choosing sites.

The protection and restoration of aquatic ecosystems depends on having a clear defendable standard of what is attainable both chemically and biologically. The best method of defining this standard is by using a reference condition based upon a set of least impacted reference sites that represent the range of natural conditions present. The quality of the bioassessments based upon this reference condition ultimately is a function of the quality of the sites used to define this reference condition. States or other regulatory entities that must establish reference sites can use this method to rapidly select a set of potential reference sites. States with a currently designated set of reference sites can use this method to add additional sites to better define the reference condition.

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APPENDIX A – Terminology.

Coverage - A digital version of a map forming the basic unit of vector data storage in ArcInfo.

Digital Orthogonal Quarter Quadrangles (DOQQ) - aerial photographs that have been digitized and corrected for earth curvature and other distortions.

Extensions - Add tools and menu choices to the basic ArcView program that are usually designed to support specific uses.

Geo-referenced - To establish the relationship between page coordinates on a planar map and known real-world coordinates.

Hydrologic Cataloging Units (CUs) - a subdivision of the Hydrologic Unit Code (HUCs) generally, although somewhat incorrectly, referred to as "HUCs".

Script – A series of commands written in the object oriented programming language, Avenue, for use in ArcView.

Sub-ecoregions (or level IV ecoregions). The hierarchical level of ecoregion designed to be used for managing water quality issues at a state level. They are of higher resolution than level III ecoregions, and are derived from data at 1:500,000 scale.

Theme - A user-defined perspective of geographic data set specified, by a coverage name and feature class or data set name, attributes of interest, a data classification scheme, and theme-specific symbology (point, line, or polygon) for drawing.

Universal Transverse Mercator (UTM)- A series of 120 coordinate systems based on the Transverse Mercator projection

View – A display of multiple themes in a single projection. The basic working environment of ArcView.

APPENDIX B – Programming Scripts.

Script "Catchment Point" for delineating catchments semi-manually

```
theView = av.GetActiveDoc
theDisplay = theView.GetDisplay
theGridTheme = theView.GetActiveThemes.Get(0)
theGrid = theGridTheme.GetGrid
thePoint = theDisplay.ReturnUserPoint
mPoint = MultiPoint.Make({thePoint})
outFName = FileName.Make("c:/gis/eco regions/poly-catch.shp")
outFName = FileDialog.Put(outFName, "poly-catch*.shp", "Output Catchment
Shapefile")
theSrcGrid = theGrid.ExtractByPoints(mPoint,Prj.MakeNull,FALSE)
theFlowDir = theView.FindTheme("Catchment Flow Direction").GetGrid
theAccum = theView.FindTheme("Catchment Flow Accumulation").GetGrid
theWater = theFlowDir.Watershed(theSrcGrid.SnapPourPoint(theAccum,240))
' create a theme
'outName = av.GetProject.MakeFileName("poly-catch", "shp")
'outFName = outName.GetCWD
'CONVERT CATCHMENT GRID TO A POLYGON
' Store the view's projection setting in a global variable
thePrj = theView.GetProjection
anFTab = theWater.AsPolygonFTab(outFName,true, thePrj)
'CREATE A THEME AND ADD IT TO THE VEIW
fthm = FTheme.Make(anFTab)
theView.AddTheme(fthm)
```

Script "fill no data holes and sinks" for preparing DEMs for hydrologic modeling

```
theView = av.GetActiveDoc
' Get active GTheme
aTheme = theView.GetActiveThemes.Get(0)
aGrid = aTheme.GetGrid
'Fix the \"no data\" holes in the elevation theme
theResult = aGrid.FocalStats(#GRID_STATYPE_MEAN,
NbrHood.MakeRectangle (3, 3, false), FALSE)
FixGrid = (aGrid.IsNull).Con(theResult, aGrid)
' fill sinks in Grid until they are gone
elevGrid = FixGrid
sinkCount = 0
numSinks = 0
while (TRUE)
  flowDirGrid = elevGrid.FlowDirection(FALSE)
  sinkGrid = flowDirGrid.Sink
  if (sinkGrid.GetVTab = NIL) then
    ' check for errors
```

```
    if (sinkGrid.HasError) then return NIL end
    sinkGrid.BuildVAT
  end
  ' check for errors
  if (sinkGrid.HasError) then return NIL end
  if (sinkGrid.GetVTab <> NIL) then
    theVTab = sinkGrid.GetVTab
    numClass = theVTab.GetNumRecords
    newSinkCount = theVTab.ReturnValue(theVTab.FindField("Count"),0)
  else
    numClass = 0
    newSinkCount = 0
  end
  if (numClass < 1) then
    break
  elseif ((numSinks = numClass) and (sinkCount = newSinkCount)) then
    break
  end
  waterGrid = flowDirGrid.Watershed(sinkGrid)
  zonalFillGrid = waterGrid.ZonalFill(elevGrid)
  fillGrid = (elevGrid <
(zonalFillGrid.IsNull.Con(0.AsGrid,zonalFillGrid))).Con(zonalFillGrid,elevGrid)
  elevGrid = fillGrid
  numSinks = numClass
  sinkCount = newSinkCount
end
' rename data set
aFN = av.GetProject.GetWorkDir.MakeTmp( "fill", "")
elevGrid.Rename(aFN)' create a theme
theGTheme = GTheme.Make(elevGrid)
' set name of theme
theGTheme.SetName("Filled"++aTheme.GetName)
' add theme to the view
theView.AddTheme(theGTheme)
```

Script "PDNP stream ordering" for producing grids of flow accumulation and direction and a vector theme of stream order based on two different hydrography data sets and a DEM

```
'Pretty Dam Near Perfect Stream Ordering
'CONVERT 1ST STREAM THEAME TO GRID
theView = av.GetActiveDoc
outFName = FileName.Make("gis/county/stream_order.shp")
newFN = FileDialog.Put(outFName, "stream_order*.shp", "Output Stream Order
Shapefile")
```

```
t = theView.GetActiveThemes.Get(0)
' convert selected features of a FTheme to Grid
anFTab = t.GetFTab
' make a list of fields
fl = {}
for each f in anFTab.GetFields
  if (f.IsVisible and (f.IsTypeNumber or f.IsTypeString)) then
    fl.Add(f)
  end
end
' check if valid conversion field exists
if (fl.Count = 0) then
  return NIL
end
'set extent and cell size for conversion if not already set
ae = theView.GetExtension(AnalysisEnvironment)
box = Rect.Make(0@0,1@1)
cellSize = 1
if ((ae.GetExtent(box) <> #ANALYSISENV_VALUE) or (ae.GetCellSize(cellSize)
<> #ANALYSISENV_VALUE)) then
  ce = AnalysisPropertiesDialog.Show(theView,TRUE,"Conversion Extent:" ++
t.GetName)
  if (ce = NIL) then
    return NIL
  end
  ce.GetCellSize(cellSize)
  ce.GetExtent(box)
end
'actually do conversion
aPrj = theView.GetProjection
aGrid = Grid.MakeFromFTab(anFTab,aPrj,nil,{cellSize, box})
if (aGrid.HasError) then
  MsgBox.Error(t.GetName ++ "could not be converted to a grid","Conversion
Error")
  return NIL
end
'RECLASSIFY 1st STREAM GRID
ReclaGrid = (aGrid.IsNull).Con(0.AsGrid, aGrid)
' check if output is ok
if (ReclaGrid.HasError) then return NIL end
'CONVERT 2nd STREAM THEAME TO GRID
t1 = theView.GetActiveThemes.Get(1)
' convert selected features of a FTheme to Grid
anFTab1 = t1.GetFTab
' make a list of fields
```

```
fl = {}
for each f in anFTab.GetFields
  if (f.IsVisible and (f.IsTypeNumber or f.IsTypeString)) then
    fl.Add(f)
  end
end
' check if valid conversion field exists
if (fl.Count = 0) then
  return NIL
end
' actually do conversion
bGrid = Grid.MakeFromFTab(anFTab1,aPrj,nil,{cellSize, box})
if (bGrid.HasError) then
  MsgBox.Error(t.GetName ++ "could not be converted to a grid","Conversion
Error")
  return NIL
end
'RECLASSIFY 2nd STREAM GRID
ReclbGrid = (bGrid.IsNull).Con(0.AsGrid, bGrid)
' check if output is ok
if (ReclbGrid.HasError) then return NIL end
'ADD STREAM GRIDS TOGETHER
sumGrid = ReclaGrid + ReclbGrid
sumGthm = GTheme.Make(sumGrid)
'RECLASSIFY STREAM GRIDS
ReclasSumGrid = (sumGrid > 0.AsGrid).Con(-100.AsGrid, sumGrid)
' check if output is ok
if (ReclasSumGrid.HasError) then return NIL end
'GET DEM AND ADD STREAMS TO IT
demTheme = theView.GetActiveThemes.Get(2)
demGrid = demTheme.GetGrid
dem1Grid = demGrid + 110
dem2Grid = dem1Grid + ReclasSumGrid
'FILL SINKS IN DEM + STREAMS GRID
elevGrid = dem2Grid
sinkCount = 0
numSinks = 0
while (TRUE)
  flowDirGrid = elevGrid.FlowDirection(FALSE)
  sinkGrid = flowDirGrid.Sink
  if (sinkGrid.GetVTab = NIL) then
    ' check for errors
    if (sinkGrid.HasError) then return NIL end
    sinkGrid.BuildVAT
  end
```

```
  ' check for errors
  if (sinkGrid.HasError) then return NIL end
  if (sinkGrid.GetVTab <> NIL) then
    theVTab = sinkGrid.GetVTab
    numClass = theVTab.GetNumRecords
    newSinkCount = theVTab.ReturnValue(theVTab.FindField("Count"),0)
  else
    numClass = 0
    newSinkCount = 0
  end
  if (numClass < 1) then
    break
  elseif ((numSinks = numClass) and (sinkCount = newSinkCount)) then
    break
  end
  waterGrid = flowDirGrid.Watershed(sinkGrid)
  zonalFillGrid = waterGrid.ZonalFill(elevGrid)
  fillGrid = (elevGrid <
(zonalFillGrid.IsNull.Con(0.AsGrid,zonalFillGrid))).Con(zonalFillGrid,elevGrid)
  elevGrid = fillGrid
  numSinks = numClass
  sinkCount = newSinkCount
end
'CALCULATE FLOW DIRECTION
flowDirGrid = elevGrid.FlowDirection(FALSE)
'CALCULATE FLOW ACCUMULATION,
flowAccGrid = flowDirGrid.FlowAccumulation(NIL)
'MAKE AND ADD CHEATED DEM FOR CATCHMENT MAKING
catch1FN = av.GetProject.GetWorkDir.MakeTmp("catch_flowdir", "")
flowDirGrid.Rename(catch1FN)
catch2FN = av.GetProject.GetWorkDir.MakeTmp("catch_flowacc", "")
flowAccGrid.Rename(catch2FN)
catch3FN = av.GetProject.GetWorkDir.MakeTmp("catch_elev", "")
elevGrid.Rename(catch3FN)
' create a theme
DirGTheme = GTheme.Make(flowDirGrid)
AccGTheme = GTheme.Make(flowAccGrid)
ElevGTheme = GTheme.Make(elevGrid)
' set name of theme
DirGTheme.SetName("Catchment Flow Direction")
AccGTheme.SetName("Catchment Flow Accumulation")
ElevGTheme.SetName("Catchment Elevation")
' add theme to the view
theView.AddTheme(DirGTheme)
theView.AddTheme(AccGTheme)
```

```
theView.AddTheme(ElevGTheme)
'GENERATE STREAMS FROM FLOW ACCUMULATION
streamGrid = (flowAccGrid < 30.AsGrid).SetNull(1.AsGrid)
'FIND INTERCEPT OF GENERATED STREAMS AND SUM OF STREAM
GRIDS
maskGrid = (sumGrid = 0.AsGrid).SetNull(sumGrid)
betterStreamGrid = streamGrid.ExtractByMask (maskGrid)
'REFINE STREAM GRID BY REGENERATING STREAM GRID BASED ON
BETTER STREAMS
weightGrid = betterStreamGrid
' calculate flow accumulation
flowAccGrid2 = flowDirGrid.FlowAccumulation(weightGrid)
' extract streams from flow acc
BestStreamGrid = (flowAccGrid2 < 2.AsGrid).SetNull(1.AsGrid)
'DO STREAM ORDERING
streamLinkGrid = BestStreamGrid.StreamLink(flowDirGrid)
StreamOrderGrid = streamLinkGrid.StreamOrder (flowDirGrid, False)
'CONVERT STREAM ORDER GRID TO A LINE
' Store the view's projection setting in a global variable
thePrj = theView.GetProjection
'newFN = FileName.Make( "gis/county/stream_order.shp" )
anFTab = StreamOrderGrid.StreamToPolyLineFTab(newFN, flowDirGrid, true,
thePrj)
'CREATE A THEME AND ADD IT TO THE VEIW
fthm = FTheme.Make(anFTab)
theView.AddTheme(fthm)
```

Script "Merge 2, 3, or 4 grids" for merging multiple raster grid data sets

```
theView = av.GetActiveDoc
themesToMerge = theView.GetActiveThemes
NumberThemes = themesToMerge.Count
YourChoice = MsgBox.Info(NumberThemes.AsString,"The source name of the
grid")
 if ( NumberThemes = 2 ) then
   aTheme = theView.GetActiveThemes.Get(0)
   aGrid = aTheme.GetGrid
   bTheme = theView.GetActiveThemes.Get(1)
   bGrid = bTheme.GetGrid
   theGridList = {bGrid}
   outGrid = aGrid.Merge(theGridList)
 end
 if ( NumberThemes = 3  ) then
   aTheme = theView.GetActiveThemes.Get(0)
   aGrid = aTheme.GetGrid
   bTheme = theView.GetActiveThemes.Get(1)
```

```
    bGrid = bTheme.GetGrid
    cTheme = theView.GetActiveThemes.Get(2)
    cGrid = cTheme.GetGrid
    theGridList = {bGrid, cGrid}
    outGrid = aGrid.Merge(theGridList)
  end
  if ( NumberThemes = 4  ) then
    aTheme = theView.GetActiveThemes.Get(0)
    aGrid = aTheme.GetGrid
    bTheme = theView.GetActiveThemes.Get(1)
    bGrid = bTheme.GetGrid
    cTheme = theView.GetActiveThemes.Get(2)
    cGrid = cTheme.GetGrid
    dTheme = theView.GetActiveThemes.Get(3)
    dGrid = dTheme.GetGrid
    theGridList = {bGrid, cGrid, dGrid}
    outGrid = aGrid.Merge(theGridList)
  end
aFN = av.GetProject.GetWorkDir.MakeTmp("merge", "")
outGrid.Rename(aFN)
' create a theme
theGTheme = GTheme.Make(outGrid)
' set name of theme
theGTheme.SetName("merged")
' add theme to the view
theView.AddTheme(theGTheme)
```

APPENDIX C - Rapid Bioassessment Habitat Assessment Form (CSU 2000)

HABITAT ASSESSMENT FIELD DATA SHEET— WADEABLE STREAMS (FRONT)

STREAM NAME	LOCATION	
STATION #_____	Lat _____ Long _____	
INVESTIGATORS		
FORM COMPLETED BY	DATE _____ AM PM	REASON FOR SURVEY

Habitat Parameter	Category			
	Optimal	Suboptimal	Marginal	Poor
1. Epifaunal Substrate/ Available Cover	Greater than 50% of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not new fall and not transient).	30-50% mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale).	10-30% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	Less than 10% stable habitat; lack of habitat is obvious; substrate unstable or lacking.
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2. Riffle Quality	Well-developed riffle and run; riffle is as wide as stream and length extends two times the width of stream; abundance of cobble. (Boulders prevalent in headwater streams).	Riffle is as wide as stream but length is less than two times width; abundance of cobble; boulders and gravel common.	Run area may be lacking; riffle not as wide as stream and its length is less than 2 times the stream width; gravel or bedrock prevalent; some cobble present.	Riffles or runs virtually nonexistent; bedrock prevalent; cobble lacking.
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
3. Embeddedness	Gravel, cobble, and boulder particles are 0-25% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 25-50% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 50-75% surrounded by fine sediment.	Gravel, cobble, and boulder particles are more than 75% surrounded by fine sediment.
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
4. Channel Alteration	Channelization or dredging absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.	Banks shored with gabion or cement, over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
5. Sediment Deposition	Little or no enlargement of islands or point bars and less than 5% (<20% for low-gradient streams) of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 5-30% (20-50% for low-gradient) of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 30-50% (50-80% for low-gradient) of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 50% (80% for low-gradient) of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

HABITAT ASSESSMENT FIELD DATA SHEET—WADEABLE STREAMS (BACK)

Habitat Parameter	Category			
	Optimal	Suboptimal	Marginal	Poor
6. Frequency of Riffles (or bends) / Velocity-Depth Combinations	Occurrence of riffles relatively frequent; ratio of distance between riffles divided by width of the stream <7:1 (generally 5 to 7); variety of habitat is key. In streams where riffles are continuous, placement of boulders or other large, natural obstruction is important; All 4 velocity/depth patterns present.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7 to 15. Only 3 of 4 velocity/depth patterns present (i.e., slow [<0.3 m/s]-deep [>0.5 m]; slow-shallow; fast-deep; fast-shallow).	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 to 25. May be only 2 velocity/depth patterns present; usually lacking deep areas.	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is a ratio of >25. Dominated by one velocity/depth pattern.
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
7. Channel Flow Status	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
SCORE _____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
8. Bank Vegetative Protection (score each bank) Note: determine left or right side by facing downstream.	More than 90% of the streambank surfaces covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
9. Bank Stability (score each bank)	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
10. Riparian Vegetative Zone Width (sc ore each bank riparian zone)	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12-18 meters; human activities have impacted zone only minimally.	Width of riparian zone 6-12 meters; human activities have impacted zone a great deal.	Width of riparian zone <6 meters: little or no riparian vegetation due to human activities.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0

Total Score _____